

# **IMPROVING QUALITY OF LIFE IN URBAN AREAS: A DECISION SUPPORT FRAME FOR AIR AND NOISE POLLUTION**

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## **Resumo**

Cidades em todo o mundo têm vindo a crescer rapidamente, com um número crescente de cidadãos, habitações, atividades económicas, indústrias. Como consequência, o número de veículos também aumentou. O número de viagens privadas e públicas para o trabalho, produtos e matérias-primas de transportes, levou a mais tráfego, ruído e poluição atmosférica. O objetivo deste trabalho é fornecer uma ferramenta que permitirá selecionar a melhor opção cada cidade, a fim de reduzir o ruído e / ou poluição atmosférica no ambiente urbano. Por esta razão, foram investigadas soluções urbanas diferentes, a fim de prevenir ou diminuir a poluição atmosférica e o ruído no ambiente urbano e melhorar a saúde humana e a qualidade de vida, com uma determinada prova da sua eficácia.

Nesta dissertação, o significado de "qualidade de vida nas áreas urbanas" relaciona o ambiente urbano a poluição atmosférica e o ruído. Há também uma ligação aos efeitos nocivos destes dois fatores ambientais (ruído e poluição atmosférica), explicado em conformidade com a saúde humana, o ambiente e a natureza. Definir estes dois tipos de poluição dá a oportunidade ao leitor de compreender melhor a importância de os controlar ou prevenir.

O processo de estudo envolveu a investigação de estratégias de mitigação e estudos de casos, onde se podem encontrar implementações dessas estratégias, recomendadas para atenuar o ruído e poluição atmosférica. Diferentes artigos e exemplos foram analisados de acordo com a natureza do problema, as estratégias implementadas, bem como a sua eficácia.

O resultado envolve diversas soluções que permitem aos responsáveis pelas políticas melhorar as condições de saúde e ambiente. Os resultados contêm planos de ação para as zonas urbanas e cidades. Fornece os métodos mais importantes a partir da informação obtida para ações de mitigação. Os resultados são na sua maioria relacionados com vegetação, limitações de tráfego e criação de barreiras para os poluentes.

**PALAVRAS-CHAVE:** Tráfego, Ruído, Poluição atmosférica, Ambiente urbano, Medidas de minimização.



## **Abstract**

Cities all over the world have been growing fast, with an increasing number of citizens, dwellings, economic activities, industries. As consequence, the number of vehicles also increased. The number of private and public journeys to work, goods and raw materials transportation, for instance, led to more traffic, noise and air pollution. The aim of this dissertation is to provide decision makers a tool that will allow them to select the best option for their cities in order to reduce noise and / or air pollution in the urban environment. For this reason, were investigated different urban solutions in order to prevent or decrease air and noise pollution in the urban environment and improve human health and quality of life, with given proves of their efficiency.

In this dissertation, the meaning of “quality of life in urban areas” relates with the urban environment and the associated air pollution and noise. There is also a connection with the harmful effects of these two environmental factors (noise and air pollution), explained in accordance to human health, environment and nature. Defining these two types of pollution gives the reader the opportunity to get to know better and to understand the important of controlling or preventing them.

The study process involved the research of mitigation strategies and urban case studies where one can find the implementation of those recommended strategies to mitigate noise and air pollution. Different articles and examples were analysed concerning the nature of their problem, the implemented strategies, and the reported effectiveness.

The result involves number of solutions that give opportunity to policy makers to improve the conditions for health and environment. The results contain action plans for urban areas and the cities. It gives concluded methods that is most important from the gained information and materials for mitigation actions. The findings are mostly connected with greenery, changing traffic limitations and creating barriers for pollutants.

**KEYWORDS:** Traffic, noise, air pollution, urban environment, mitigation measures



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## **List of Symbols**

Al - Aluminum

CO<sub>2</sub> – Carbon dioxide

CO – Carbon monoxide

dB (A) - A-weighted decibels

EEA – European Environment Agency

END – Environmental Noise Directive

HC<sub>S</sub> – Hydrocarbons

K - Kalium

Na – Natrium

NO<sub>x</sub> – Nitrogen oxides

O<sub>3</sub> – Ozone

PAH – Polycyclic Aromatic Hydrocarbons

PM – Particulate matter

QOL – Quality Of Life

Si - Silicon

SO – Sulphur oxide

TSAP – Thematic Strategy on Air Pollution

WHO – World Health Organisation



# 1 INTRODUCTION

## 1.1 GENERAL OVERVIEW

Sustainable urban planning is one of the most relevant concerns, in the moment. The acknowledgement of the scarcity of natural resources, the increasing pollution, and the natural hazards has brought to light the need for a different type of development more focused in the survival of the Humanity.

Now, it is a basic assumption that the development of countries, regions and cities should be grounded on sustainability principles that will allow:

- *preservation of natural resources* – with an efficient use, waste reduction, reuse and recycling concerns;
- *minimize pollution and maximize quality of life* – with preventive and mitigation measures, including more restrictive pollution levels, regarding both emission and concentration, and
- *adaptation and mitigation to climate change* concerns that will allow to reduce the negative effects of related natural disasters.

The underlying intention is to create conditions for a proper urban development that meet the needs of the present generations, will guarantee the survival of future generations and, will preserve the well-being and quality of life of the city inhabitants in the future (UN-WCED, 1987).

Concerning quality of life and well-being, one can consider several factors such as economic, social and environmental factors. Presently, transportation, with related noise and air pollution problems are elements that cannot be dissociated from the urban environment. That is why they became such an important subject for both the citizens and policy-makers.

City growth always includes more noise and air pollution that results in more polluted environment, negative ecosystem and has a negative influence in the population's health.

It affects all social groups. Although social groups with higher income and knowledge can provide better quality of life and healthy environment for themselves by simply moving into more ecological friendly environments outside the city, but not everyone can afford it. Here is where policy-makers can make the difference. They can provide better quality of life for all the inhabitants of their city regardless of their economic situation or social status.

Everyone has the right to live in good and healthy environment. Different studies (EEA, 2015) (EEA E. E., 2014) have shown that, nowadays the health risk caused by air and noise pollution is high, and can lead to health risks as severe as mortality (EEA, 2015). Every year certain number of people is dying due to outdoor polluted air and noise worldwide. With road transport, environmental noise poses very high risk for the population and their health. Every year, more than a 10,000 people are victims of premature death because of noise pollution in Europe (EC, 2016) and about 500,000 due to air pollutants (EEA, 2015).

Country	PM <sub>2.5</sub>	O <sub>3</sub>	NO <sub>2</sub>
Austria	6 100	320	660
Belgium	9 300	170	2 300
Bulgaria	14 100	500	700
Croatia	4 500	270	50
Cyprus	790	40	0
Czech Republic	10 400	380	290
Denmark	2 900	110	50
Estonia	620	30	0
Finland	1 900	60	0
France	43 400	1 500	7 700
Germany	59 500	2 100	10 400
Greece	11 100	780	1 300
Hungary	12 800	610	720
Ireland	1 200	30	0
Italy	59 500	3 300	21 600
Latvia	1 800	60	90
Lithuania	2 300	80	0
Luxembourg	250	10	60
Malta	200	20	0
Netherlands	10 100	200	2 800
Poland	44 600	1 100	1 600
Portugal	5 400	320	470
Romania	25 500	720	1 500
Slovakia	5 700	250	60
Slovenia	1 700	100	30
Spain	25 500	1 800	5 900
Sweden	3 700	160	10
United Kingdom	37 800	530	14 100
Albania	2 200	140	270
Andorra	60	4	0
Bosnia and Herzegovina	3 500	200	70
former Yugoslav Republic of Macedonia, the	3000	130	210
Iceland	100	2	0
Liechtenstein	20	1	3
Monaco	30	2	7
Montenegro	570	40	20
Norway	1 700	70	200
San Marino	30	2	0
Serbia <sup>(a)</sup>	13 400	550	1100
Switzerland	4 300	240	950
<b>Total <sup>(b)</sup></b>	<b>432 000</b>	<b>17 000</b>	<b>75 000</b>
<b>EU-28 <sup>(b)</sup></b>	<b>403 000</b>	<b>16 000</b>	<b>72 000</b>

**Notes:** <sup>(a)</sup> Including Kosovo, under the UN Security Council Resolution 1244/99.

<sup>(b)</sup> 'Total' and 'EU-28' figures are rounded up or down to the nearest thousand.

Figure 1 - Premature deaths attributable to fine particulate matter (PM<sub>2.5</sub>), ozone (O<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>) exposure in 2012 in 40 European countries and the EU 28. (EEA, 2015)

In Figure 1 it is shown the number of people in Europe estimated to be exposed to different air pollutants, namely: PM<sub>2.5</sub>, NO<sub>2</sub> and O<sub>3</sub>, the most relevant factors regarding health concerns.

But is not only the human health (and other living beings) that is at risk. Air pollution, in particular and the vibrational part of noise, also “damages” buildings. If we consider urban areas and especially the historical parts of the cities, ancient buildings often look dark (air pollution) and cracked (vibrations) (Slezakova, et al., 2011).

In this dissertation, will be discussed air and noise pollution from road transport in urban areas, how it affects the environment and the population and which strategies for mitigating pollution can be used to mitigate those problems in order to improve quality of life for inhabitants.

The relevance of this subject, that has been under the spotlight for decades, is unavoidable. For example, the unwanted noise and air pollutants were highlighted as negative factors mostly since the middle of the 20th century (Wu, 2008) (E. Jr. Taylor, F. Pitelka, & T. Clegg, 1991).

Having no information or the lack of information makes hard to focus, handle and try to resolve or mitigate problems concerning air pollution and noise. However, even when you have all data needed, it is still hard to deal with air pollution and noise problems, mostly within the boundaries of the city centre. There is also a special concern in situations, even more serious, in countries without any knowledge about their level of air pollution and noise, when they discover that they are dealing with higher levels of pollution, which makes the problem harder to resolve. In these countries, apart from the mitigation policies and strategies needed, there is an increasing concern related with the attitude of the population, not so aware of the health related effects and so not willing or not so ready to change their mobility patterns into soft modes or public transportation, less pollutant to the environment.

In order to help decision-makers, in the process of selecting the best options to reduce pollution levels, it was considered relevant to gather the available information about different cities and the already applied solutions together with the outcomes of that implementation and the confrontation with the intended results.

Countries, in all stages of development, concerning air pollution and noise awareness need good information about different ways to reduce traffic congestion, decrease air pollution and noise levels in urban areas.

Sometimes a solution is unique. Every city can have – or may need to have - its specific and individual solution for dealing with air pollution and noise. Cities have characteristics of their own such as topography, which can be flat or hilly, density (with high, medium or low-density cities), ancient or new cities, with historical centres, with bay areas, with seaside areas, etc., or even its shape: cities can be radial, linear, in grid and star shaped (Jacobs, 1961).

In this dissertation, there is a discussion about the problems connected with transportation, in particular, road transportation. It also presents its relation with environmental pollution, an analysis on the existing policies and guidelines to prevent them, along with a collection of case studies in which different solutions are already in place.

Provided work can be helpful, firstly, to inform citizens that can learn about the consequences of excessive levels of air pollution and noise, and the nature of changes to the environment and human lives if we will or will not improve the present situation. Secondly, this document will gather the relevant information for policy-makers who are willing to reduce traffic emissions in the cities, whether they already started some action plans or if they are just beginning to take their first actions and do not have

any experience yet. They will have a chance to check a list of solutions for cities or urban areas, with the suggestions of possible changes, additions or restrictions in order to improve quality of life, decrease traffic emissions and the levels of polluted air and noise.

The provided knowledge is important, as for policy makers, also for citizens. Although the methodology gathers some new findings in the given field of study, the main part of it is based on the methods that were being established and researched in the last decades, since the problem became obvious. The subject is of the major concern among the public and private sectors.

## **1.2 PURPOSE OF THIS DISSERTATION**

Considering the fact that the situation in Europe is still not controlled, regarding the number of persons exposed to noise levels higher than the recommended both by World Health Organization (WHO) (WHO, Guidelines for Community Noise, 1999) and in the Environmental Noise Directive (END) (EU, 2002), it is mandatory that urban authorities and city planners to take some action.

The latest reports from the European Environmental Agency (EEA) reveal that in 2007 more than 67 million inhabitants in Europe were exposed to excessive noise from road traffic, that means the allowed minimum, which equals the noise level 55 dB during the day and 50 dB during night. The latest available results, from 2012 and when compared to the results of the year 2007, revealed an increase in the number of people that are exposed to excessive road traffic noise (EEA E. E., 2016).

These results are easy to understand, as transport is part of quotidian lives. It has brought many changes to everyday life, both with positive and negative effects. On the positive side, it helps people to be more active, mobile and cover long distances in less time. On the negative side, it brings traffic congestion, air pollution, noise, and all related harmful effects to our health; disturbing our everyday activities such as working, studying and sleeping.

At some time, it became necessary to take it under control, at municipal level, by reducing the number of private vehicles, in order to reduce traffic congestion and consequently decrease air pollution and noise. Personally, for my country- Georgia, the most relevant sources of pollutants derive from road traffic very uncomfortable and annoying. The noise from vehicles in general brings disturbance for daily activities, both indoors and outdoors, as the acoustic insulation of buildings is not adequate for such extreme conditions. Also air pollution and the peculiar topographic conditions of my city Tbilisi, makes very difficult an effective dispersion of air pollutants, and it is hard to breathe the polluted air (Numbeo, 2016).

As inhabitant or as a tourist, I am always trying to stay far from roads and urban streets, trying to keep away from the pollution that comes from transport system. And, naturally, as any other person, I always look for the nearest natural green areas, with water streams or fountains, different flowers, plants and the sound of birds, the places where most of the people like to be while being outside. From experience of traveling or simply from walking in the city where I live in, I am always looking to go into the nature, far from transports and pollution. Contact with nature, clean air and less noisy places is very important in people's lives, and the more opportunity one gets the healthier and psychologically stronger he/she will feel (Mitten, 2009). But, unfortunately, not everyone has the chance or opportunity to go away into the nature and far from busy streets that is one of the reasons why it urges to take actions to reduce air pollution and noise.

So, the goal is to find solutions for the cities and urban areas that are possible to implement and effective.

That is the principal motivation and purpose of this dissertation: to provide decision-makers with a tool that will allow them to find “the best” solution for their particular problem, concerning a big and important issue nowadays present in our lives: excessive transportation traffic and related air pollution and noise in the cities and urban areas.

### 1.3 STRUCTURE OF DISSERTATION

The structure of the present dissertation consists in five chapters.

The dissertation starts with an introduction to the theme, to the relevance of the topics in the international context and with an explanation of the motivation for the subject, in the present chapter: *chapter 1 - Introduction*.

The next chapter: *chapter 2 – Literature Review* is devoted to the three main subjects of this dissertation: quality of life, air pollution and noise. Here one can find the main definitions, concepts and terms associated with each of those topics. It is also in this chapter made the connection between the key dimensions of quality of life and the right for a person to have a good quality of life. In those dimensions is also included the right to breathe unpolluted air and live in a noiseless environment. That is the reason why the following points explain with more detail the definition of air pollution, which are the most relevant sources and how it can damage our health, environment and nature. The same was performed regarding noise.

*Chapter 3 – State of the Art Review* is dedicated to the methodology followed in the present dissertation. It is important to show the development of the work in this dissertation and how it can be used in the future to improve citizens’ quality of life. The methods that were learned in this work, will be discussed in this chapter. In addition, the methods from the international projects will be gathered. Next the focus is the relevant scientific articles and practical experiments with reported results were reviewed, gathered, organized and discussed several strategies and methods for reducing air pollution and noise. Here are discussed different methods as using greening spaces, passive barriers, changing traffic policies and speed limitation or alterations in road pavements, introduction of vegetation and noise barriers.

The following is the *chapter 4 – Implementation*, develops the methodology that decision-makers could use if they need to decide which is or which are the most adequate solution(s) for their cities. The gathered methods are directed to the capital of Georgia – Tbilisi. The city was chosen in order to examine the implementations. The chapter is helping decision makers to choose, the choice of revealing why some solutions did not work in certain context although theory defends good results was also contemplated, as one cannot implement all solutions in every urban environment. For this reason, is very important to perform an accurate analysis, respecting the urban area in presence, it’s peculiarities in terms of response to noise and air pollutants dispersion, considering simultaneously the already implemented strategies and the efficiency rate they achieved.

The last part, *chapter 5 – Conclusions*, is where are gathered the best results of the analysed articles, revealing which were the more efficient methods and strategies for reducing noise and air pollution. where it is possible to notice some considerations about the most effective strategies – the ones that demonstrates to be more efficient in diverse situations. It is highlighted how it is possible to use this dissertation in a useful way when a municipal decision maker needs to choose the best technical option to reduce air pollution, noise, or even bot at the same time. Regarding future works and considering the implementation of these solutions in public areas, would be of great importance to understand the citizens’ perception: if they agree with the solutions, if the notice any difference (in terms of acoustic environment), if they rather have given their opinion first.



# 2

## LITERATURE REVIEW

### 2.1 INTRODUCTION

This chapter will consist of a theoretical introduction to the three themes of this dissertation: quality of life (in urban areas), air pollution and noise.

In fact, recently was released a study (Science for Environment Policy, 2016) in which it was highlights the influence of the different social-economic status on the evaluation of the health effects and quality of life of citizens living under polluted circumstances. In that study they state that social-economic inequalities “may arise as a result of either increased exposure to pollution, or increased sensitivity to pollution, or increased vulnerabilities, or, perhaps most likely, a combination of all three.”. This study also confirms one of the challenges faced during this dissertation. When looking for information concerning case studies, later analysed in *chapter 3 – Methodological approach*, the reported studies concerned different areas and scales, hardly consider the socio-economic status as a variable, and assess exposure levels both for noise and air pollution on average regardless of the effective characteristics of each building. In fact, it was quite difficult to find studies concerning only exterior urban areas.

As an urban citizen, each one wants to have “quality of life”. It consists of a nice atmosphere combined with clean air, calm streets, green spaces and other public places where the level of polluted air and noise are not disturbing peoples’ health.

As reported, by environmental agencies and the European in particular, one of the biggest problems of this and previous centuries are air pollution and noise, greenhouse gases and climate change that are mostly arising of the industrialization. One of the major sources of greenhouse gases, air pollution and noise is road transport. Despite of some improvements over past decades, road transport is still responsible for one fifth of greenhouse gas emissions (EEA E. E., 2016). It is also the main reason, in many European countries, for higher concentrations of air pollution than the admissible according to the EU directives.

However, over the past 25 years, the European directives on noise and air pollutants emissions have been limiting maximum pollutant levels setting higher standards for fuel quality, stricter policies and technological standards for vehicle emissions and establishing air quality limits, and noise thresholds.

So here, there is a dichotomy, at one-point urban development and transportation makes life easier, and makes possible to manage different things without losing much time, with many benefits to society, like employment and economic growth, together with the movement of people and goods; but at another point it raises dangers for citizens’ health, environment and nature.

Now, the use of public transportation is not generalized as in many cities it does not provide enough or good connections between different areas of the city without losing a lot of time during the day. Frequently, time that families do not have to spend with each other. Therefore, nowadays having a

private vehicle can no longer be considered a luxury and it is affordable for different socio-economic classes of people. This opportunity significantly increased the number of private vehicles in circulation in many cities. The positive part, the comfort of going faster from point A to B, time by time revealed a negative side, in many cases, and brought huge traffics congestions, many of which caused by wrong planning, architecture, and big concentration of vehicles over short periods of the day – peak hours. That implies that the problem is not only losing comfort and time but, most important, is that environment is becoming more polluted. In particular, in what concerns air pollution and noise, that are harmful for environment and human life, but also because their connection to the main sources of greenhouse gases and are one of the contributors for climate change.

A brief explanation of the topics considered in this dissertation will be given in the following points.

## **2.2 QUALITY OF LIFE**

### **2.2.1 INTRODUCTION**

Quality of life defines success of cities in the future for social and economic factors. One can think about ‘quality of life’ as the “happiness and well-being of inhabitants” (Eurostat, 2015). Well-designed buildings and public spaces in a well-planned urban environment can create safe, clean, calm and nice atmosphere. The living environment plays big role on inhabitants’ life affecting their daily life and health. Many residents consider the fact that their well-being and economy depends on the quality of the surrounding environment (EEA E. E., 2009).

### **2.2.2 QUALITY OF LIFE INDICATORS**

The quality of life (QOL) concerns many people worldwide and includes different dimensions started from physical finished with socio-economic, cultural, environmental and psychological ones. In general, the term “Quality of Life” is associated with overall well-being in society. However, different authors agree that there is not a unique definition of the term and have their points of views on the dimensions that should be evaluated to assess the quality of life (Keles, 2011). According to them the definition of Quality of Life (QOL) has in general three dimensions:

- the individuals’ impression of his life and situation, in the local context and not in the country level;
- The individuals’ interaction and/or coexistence with the society and different areas of knowledge;
- The personal views (subjective interpretation) regarding objective information and living conditions.

These authors agree that income per capita is a very weak indicator for defining humans’ well-being, and should be replaced with dimensions such as health, education and political participation (Keles, 2011). Even though, some of those authors doubt about the accuracy of those dimensions for measuring the quality of well-being, considering that each individual can judge the same situation in a different way, according to their values and levels of satisfaction (Cella, 1994). Some other attempts to measure quality of life with income, divorce rate or crime rate, also failed to reflect citizens’ subjective interpretation on quality of life (Lee & Sener, 2015).

It is clear that the judgement on quality of life depends on the personal values of the citizen, and at the same time, includes the emotions coming from the cultural values of the society he belongs to (Hofstede,

1984). For example, people in Canada and United States tend to rate their lives and happiness on higher level and in more optimistic way, than people in East Asia, who tend to be more pessimistic (Suh, 2000).

In this line of thought, it is clear that citizens' interpretation on the concept of 'quality of life' is quite diverse from the one associated with some statistical and economic related parameters. In 1999, Michelle Dobré made an interesting research asking people '*What comes first to your mind when I say quality of life in your city and region?*'. People gave different answers, but the content of their answers related mostly with clean and non-polluted environment. When asked to define the meaning of quality of life, even belonging to different age groups, almost all the respondents connected their answers to being close to nature, to hear the sound of birds, to be close to water, or to live in suburbs with a good connection to the city by public transport and in a good environment. People are happy to be living outside the city centres and have their gardens (EEA, 2009).

Even though, in statistical terms and for comparison purposes, were defined a set of dimensions that according to Eurostat, would be able to represent a measure of quality of life. In that set are included *eight plus one* dimensions that represent different aspects of quality of life (Eurostat, 2015). The first eight relate to the functional capabilities of the citizens in pursuing effectively their self-defined well-being, according to their values and priorities. The additional dimension belongs to personal achievement satisfaction and life well-being. Those dimensions are:

1. Material living conditions;
2. Productive or main activity;
3. Health;
4. Education;
5. Leisure and social interactions;
6. Economic and physical safety;
7. Natural and living environment;
8. Governance and basic rights;
9. Overall experience of life.

The two first dimensions relate with people's priorities. They concern their level of intended self-comfort (individual perception) and the way they can or cannot achieve them together with the recognition as individuals, either from voluntary work (social recognition) or from professional work (through their income and the role that plays in peoples' lives and on the significant impact it has on their quality of life). One can relate these two dimensions, on the positive side with socialization with other people, creativity, enjoyment and fulfilment; but on the negative side, people can feel insecurity, discrimination, fear of physical injury, or psychological constrained.

The next three dimensions also relate with quality of life, are all connected, have major impact on people's sense of well-being, happiness and life satisfaction. *Health* impacts can make human life shorter, delay economic and social development and affects the other dimensions of quality of life like *education, leisure and social interactions*. Noise and air pollution interfere with *educational* activities as they reduce the competences to learn, to understand and preserve cultural heritage. In that context, it has a major impact on human civilization, economic growth and quality of life and it can limit the access to good jobs and increase the risk of poverty. Above all, education allows people to understand better the world they live in. Leisure and social interaction include not only the time people spend outside their productive activities but also the "social capital", there is to say, the ability of individuals and society to have a better health, higher chances to find a job and living with a better neighbourhood.

Economic and physical safety is a dimension that incorporates risks that can threaten material or psychological conditions of individuals, such as losing job, weak health, aging, financial crisis, violence and crime, that can weaken the quality of life.

The seventh dimension, regarding the environment, not only affect human well-being and health, but also cause natural disasters. It has a major relevance in quality of life, human health and well-being and involves clean water, noise-free working and living areas and access to nature and green spaces. Indirectly is associated with economic prosperity and inequality, affecting property prices and housing conditions. Concerning Governance and respect of human rights, it is very important for citizens to have the rule of law and guarantee equity on treatment (from police, the judicial system and the administration).

The last dimension is the ultimate goal of any EU policy. The overall experience of life takes into account the well-being of the persons integrating the diversity of experiences, choices, priorities and values of the individuals. The subjective well-being includes three sub-dimensions: *life satisfaction* (or evaluation), based on intellectual assessment; *affects*, or the presence of positive feelings and absence of negative feelings; and the last one is *eudaemonist*, that means that one's life has a meaning, and is focused on self-realization.

In general terms, the environment where people live in has a big influence on their well-being, mental and physical life. It depends on the use of natural resources, urbanisation and sources of pollution. There is a relation between human health and urban environment factors, which include socio-economic and cultural context. The critical environmental conditions that comes from air pollution, noise, water pollution and loss of natural areas are the main reasons for some of the present diseases, and are major public health issues (EEA E. E., 2016).

### 2.2.3 INDEX FOR QUALITY OF LIFE IN EUROPE

In 2013, European residents, considering the *eight plus one* variables evaluated on the quality of life index rated their overall life satisfaction with 6 or higher on a scale of 0 to 10, which represents an average satisfaction index of 7.1 (Eurostat, 2015). According to the same study, the highest satisfaction rates regarding quality of life (7.8) concerned people with higher education or training. On average, the least satisfied persons were unemployed and inactive people (5.8). Figure 2 show these results.

This statistic based on 2013 data (Eurostat, 2015) clearly reveals that material living conditions, social relationship and health status are in line with life satisfaction. However, the most negative effect on life satisfaction concerns poor health status. People rated the purpose of life, on average, higher than their overall life satisfaction; this aspect applies to eudemonic sub-dimension of well-being. The subjective and personal measures, such as meaning of life and life satisfaction, are reliable measures supported by international studies and guidelines (EEA, Ensuring quality of life in Europe's cities and towns, 2009). Subjective well-being measured through overall life satisfaction, and socio-demographic factors (like age, income or education that leads to different preferences and life expectations) shows that younger people are demonstrate higher results for life satisfaction. With higher age, the level of satisfaction is decreasing, until the age group 65-74. However, according to the same study, in some countries, such as Denmark, the Netherlands, Sweden, Norway, the United Kingdom and Switzerland, people with 65 years or older have higher results of life satisfaction than the group of young people.

	Age Group						Total
	16–24	25–34	35–49	50–64	65–74	75+	
<b>EU-28</b>	<b>7.6</b>	<b>7.3</b>	<b>7.1</b>	<b>6.9</b>	<b>7.0</b>	<b>6.8</b>	<b>7.1</b>
Belgium	7.8	7.6	7.6	7.5	7.5	7.4	7.6
Bulgaria	5.8	5.4	4.9	4.6	4.3	3.9	4.8
Czech Republic	7.7	7.3	7.0	6.6	6.6	6.5	6.9
Denmark	8.1	7.8	7.8	7.9	8.6	8.4	8.0
Germany	7.6	7.3	7.2	7.0	7.4	7.5	7.3
Estonia	7.2	7.1	6.5	5.9	6.1	6.0	6.5
Ireland	7.7	7.4	7.2	7.3	8.0	7.8	7.4
Greece	7.0	6.4	6.3	6.0	5.9	5.5	6.2
Spain	7.4	7.1	6.9	6.7	6.9	6.4	6.9
France	7.6	7.3	7.0	7.0	7.0	6.7	7.0
Croatia	7.5	7.2	6.4	6.1	6.0	6.0	6.3
Italy	7.0	6.8	6.8	6.6	6.4	6.3	6.7
Cyprus	6.9	6.4	6.1	5.7	6.1	6.0	6.2
Latvia	7.3	7.0	6.4	6.2	6.1	6.0	6.5
Lithuania	7.8	7.3	6.7	6.3	6.5	6.1	6.7
Luxembourg	7.8	7.7	7.4	7.3	7.4	7.3	7.5
Hungary	7.1	6.7	6.2	5.8	5.9	5.6	6.2
Malta	7.6	7.5	7.1	6.9	7.1	7.0	7.1
Netherlands	7.9	8.0	7.6	7.7	7.9	7.9	7.8
Austria	8.4	8.1	7.7	7.7	7.7	7.6	7.8
Poland	8.1	7.8	7.4	7.0	6.9	6.9	7.3
<b>Portugal</b>	<b>7.5</b>	<b>6.8</b>	<b>6.3</b>	<b>5.7</b>	<b>5.9</b>	<b>5.6</b>	<b>6.2</b>
Romania	8.0	7.5	7.4	6.9	6.7	6.2	7.2
Slovenia	7.8	7.4	7.1	6.6	6.6	6.4	7.0
Slovakia	7.6	7.4	6.9	6.6	6.7	6.1	7.0
Finland	8.2	8.3	8.1	8.0	8.0	7.7	8.0
Sweden	7.9	7.8	7.9	7.9	8.3	8.1	8.0
United Kingdom	7.5	7.3	7.1	7.1	7.7	7.5	7.3
Iceland	8.2	8.0	7.9	7.8	7.9	8.1	7.9
Norway	8.0	7.8	7.8	7.9	8.1	7.9	7.9
Switzerland	8.1	7.9	7.9	8.0	8.4	8.4	8.0
Serbia	6.1	5.5	4.9	4.6	4.8	4.6	4.9

Figure 2 - Life satisfaction, by age group and country (mean rating), 2013 (Eurostat, 2015)

In overall, people in couples or with children show higher results for life satisfaction, than people who live alone, a fact referred to socialization, with the lowest level of life satisfaction given by unemployed people. There is a clear connection between income and life satisfaction, first discovered by Easterlin in 1974 (Easterlin, 1974). He observed that wealthier people were happier than poorer. Education has a very strong impact on life satisfaction, not only because it enables people to have satisfying and better-paid jobs, but also because people recognize value in education (Eurostat, 2015) .

Life satisfaction shows how people rate their life in general. The word “life” refers to all areas of person’s existence. This term focuses on how people feel “these days” and aims to reflect people’s overall level of satisfaction. Meaning of life refers to the value and purpose of life, important goals of life and spirituality. People should think of what makes their life and existence important and meaningful (Eurostat, 2015).

## 2.3 AIR POLLUTION

### 2.3.1 INTRODUCTION

Air pollution is related with harmful elements in the air that we breathe that can endanger personal health as they are greater than the safe limits, in particular the ones established the international organizations

as WHO and EU. Air pollutants causes harm for the environment and in Humans mostly due to increasing urbanization, related with excessive gases, dust or fumes, in dangerous concentrations. According to the European Environment Agency, there are several sources of air pollution (EEA, 2015), among which one can find:

- Agricultural activities;
- Energy production and distribution;
- Natural phenomena;
- Waste (landfills), coal mining and long-distance gas transmission;
- Road transport;
- Fuel combustion.

The air is cleaner today than it was two decades ago, but still percentage of polluted air is not acceptable for safe environment (EEA, 2008). In 2008, EEA published, that road transport is the main polluter of the environment. The report states that air pollution coming from motor vehicles has replaces the coal smoke in many countries and it is being as the major cause for concern. The continuing growth of vehicle users means that taking effort to reduce emissions from individual vehicles will be harder and it may be even overtaken by increased traffic noise. In Eastern Europe the use of old cars, that do not meet modern pollution control requirements, is in continued use, and this can be more difficult to control pollution from this source.

Except human health, air pollution can harm the buildings, including historical buildings that have cultural and historical value. According to EEAs report- “Air quality in Europe-report 2015” (EEA, 2015), the costs of damage to buildings from air pollution in Europe were estimated to be around EUR 1 billion in 2010.

During last decades the levels of CO, PM<sub>10</sub> and SO<sub>2</sub> have decreased, but considering the results for some countries the level of NO<sub>x</sub> and NO<sub>2</sub> have not made significant change. The results from analyses show that gypsum is the main component of black crusts that exist on monuments (Slezakova, et al., 2011). After diagnosing, it was confirmed that the major source of PAHs in black crusts was traffic emissions.

Polycyclic Aromatic Hydrocarbons (PAHs) are the group of more than a 100 chemicals that are released from burning oil, gasoline, coal, trash, tobacco, etc. (Specialized Information Services, Environmental Health and Toxicology, 2015). Mostly they occur from activities such as driving, agricultural burning, and paving with asphalt. People are mainly exposed to PAHs by breathing polluted air and vehicle exhaust. Exposure to PAHs are connected with lung, skin and liver cancers. If the exposure is with large amounts it can lead to death.

The biggest and most important problem for deposition of atmospheric pollutants on surfaces of buildings is that it affects the facades of historical monuments that bring blackening effect. Impacts for buildings from air pollution can be permanent, but it can lead to loss of irreplaceable monuments forever.

In December of 2008, samples of black crust were collected in the Monastery of Serra do Pilar that stands on the left bank of the river Douro in Porto, situated approximately 1,5km near to the monitoring station. This monument was built in the sixteenth century and the samples of black crust were taken from the different points on the monument, with different solar orientation and with rainfall shelters. The analyses from black crusts samples show that it was 3 and 7 mm thick and had dendritic surface (Slezakova, et al., 2011). Porto’s subsoil mostly consists of granite, and most of the historical monuments in this region are built with this material. The minerals, that Porto’s granite is composed with, are rich with Si, Al, K and Na. regarding gypsum formation, after black crusts are already on monuments, that are built with calcium carbonate rich rocks, part of them (calcium ion) is being supplied

by the surface stone itself, and another part (sulphate ion) is supplied from the rain water. According to this, whenever rain water dries up, the gypsum crystallizes originating black crusts. Due to this processes, the continuous build-up of black crusts is progressing on the monuments getting thicker.

According to different analyses that were made from the black crusts on the Serra do Pilar monument, the results show that sources for different particulates are emissions from traffic and also from a power plant that is situated nearby (Slezakova, et al., 2011). The presence of PAH (polycyclic aromatic hydrocarbon) justify that it is mainly emitted by traffic emissions, and considering the high levels of plenanthrene in the air and in black crusts, makes it obvious that the growth of black crusts on monument is influences by traffic emissions.

The existence of considerable levels of PAHs on buildings and monuments, leads to additional risks for human health. Having specific knowledge is needed to define appropriate safety equipment and procedures while cleaning the buildings on order to keep human health and the heritage in the safe conditions. According to results, after analysing the Monastery of Sera do Pilar (Slezakova, et al., 2011), in order to protect public health and historical heritage in the cities, the effort reducing traffic emissions are essential. Historical monuments in the urban areas act as the passive repositories for air pollutants in the surrounding atmosphere.

### 2.3.2 AIR POLLUTION INDICATORS

Air pollution can be defined as the existence of pollutants in the atmosphere that can bring harm to human health, environment and cultural heritage. The quality of air that people breathe, depends in general on many factors, such as the local landscape and meteorology, the mix of emission sources in the given area, and how all this can affect the formation of the pollutants (EEA E. E., 2016).

Urban air pollution is usually analysed by indicators measuring exposure to PM and ozone. PM contains the smallest pieces of solid or liquid matter, that come from human or natural source of pollution, which normally originates from diesel engines and from industrial, public, commercial and residential heating. It also comes from meteorological and natural conditions. For example, the higher the temperature is it brings stagnant air with high number of pollutants, the lower it is, and it brings more emissions from fuel use and combustion.

One of the most important source of the most harmful air pollutant is the road transport that mostly occurs in the active areas, where people live and work, for this reason, the pollution released by vehicles is very important (Figure 3).

According to the document from EEA about the “*Emissions of air pollutants from transport*” (EEA E. E., 2016) the main air pollutants coming from the road transport are:

- **Carbon dioxide (CO<sub>2</sub>)** - is the main product of fuel burning in vehicle engines, along with water. CO<sub>2</sub> is the most significant GHG influencing climate change, posing a threat to public health and the environment. Natural CO<sub>2</sub> is produced by the terrestrial biosphere and the ocean. But humanization replaced natural carbon cycle by burning coal, oil, natural gas, and wood. By developing industry, these activities have increased in scale and distribution. Among other greenhouse gases, carbon dioxide was the first to be shown rise.
- **Hydrocarbons (HCs)** – are produced from incomplete or partial combustion and are toxic to human health. HCs, and particularly the volatile organic compounds (VOCs), contribute to the formation of ground-level ozone and photochemical smog in the atmosphere. Ozone irritates the eyes, damages the lungs and aggravates respiratory problems.



### Sources of air pollution in Europe

Air pollution is not the same everywhere. Different pollutants are released into the atmosphere from a wide range of sources, including industry, transport, agriculture, waste management and households. Certain air pollutants are also released from natural sources.



**1 /** Around 90 % of ammonia emissions and 80 % of methane emissions come from **agricultural activities**.

**4 /** **Waste (landfills), coal mining and long-distance gas transmission** are sources of methane.

**2 /** Some 60 % of sulphur oxides come from **energy production and distribution**.

**5 /** More than 40 % of emissions of nitrogen oxides come from **road transport**.

Almost 40 % of primary PM<sub>2.5</sub> emissions come from transport.

**3 /** Many **natural phenomena**, including volcanic eruptions and sand storms, release air pollutants into the atmosphere.

**6 /** **Fuel combustion** is a key contributor to air pollution – from road transport, households to energy use and production.

**Businesses, public buildings and households** contribute to around half of the PM<sub>2.5</sub> and carbon monoxide emissions.

Source: EEA

Figure 3 - Sources of air pollution in Europe (EEA E. E., 2016)

- **Carbon monoxide (CO)** – is a product of incomplete combustion, which occurs when the carbon in the fuel is only partially oxidized, forming CO and not CO<sub>2</sub>. It is colorless and odorless but highly toxic. Direct exposure to CO reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Like HCs, CO also contributes to the formation of ground-level ozone and smog.
- **Particulate matter (PM)** - which is a product of incomplete combustion and a complex mixture of both primary and secondary PM. 'Primary' PM is the fraction of PM that is emitted directly into the atmosphere, whereas 'secondary' PM forms in the atmosphere following the release of precursor gases (mainly Sulphur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), ammonia (NH<sub>3</sub>) and some VOCs). In terms of its potential to harm human health, PM is one of the most important pollutants, as it penetrates into sensitive regions of the respiratory system and can cause or aggravate cardiovascular and lung diseases and cancers.
- **Nitrogen oxides (NO<sub>x</sub>)** which constitute a group of different chemicals that are all formed by the reaction of nitrogen — the most abundant gas in air — with oxygen. NO<sub>x</sub> comprises colourless nitric oxide (NO) and the reddish-brown, very toxic and reactive nitrogen dioxide (NO<sub>2</sub>). NO<sub>x</sub> emissions also lead to the subsequent formation of 'secondary' PM and ground-level ozone in the atmosphere, and cause harm to the environment by contributing to the acidification and eutrophication of waters and soils.

These pollutants derive mostly from three types of vehicle emissions (EEA E. E., 2016):

- **Exhaust emissions:** produced by combustion of different petroleum products such as diesel, petrol, natural gas and liquefied petroleum gas. These fuels are mixtures of different hydrocarbons. In the “perfect” engine, during combustion process the nitrogen would remain unaffected in the air. But in reality the engines emit many different pollutants, and their amount is dependent on the type of fuel.
- **Abrasion emissions:** Produced from mechanical abrasion of vehicle parts. Significant levels of PM and heavy metals that can be produced by vehicle’s tires, brakes, clutch or the road surface wear.
- **Evaporative emissions:** Result of vapour that is escaping from vehicle’s fuel system. The evaporative emissions are very important and the can be emitted any time when the fuel is in the tank, even when the engine is off.

### 2.3.3 HEALTH EFFECTS FROM AIR POLLUTION

Air pollution is harmful for health and environment. Polluted air is one of the biggest environmental risk for health (WHO, 2014). Although during last year’s many cities are trying to reduce air pollution, the risk for damaging health and environment is still high. It is responsible for 80% of cases of early death, lung diseases and lung cancer Figure 4. In 2012, outdoor air pollution was the cause for premature death of 3.7 million people. Air pollution causes heart disease, stroke and increases the incidence of a wide range of diseases such as respiratory and cardiovascular diseases and cancer, effecting health in short- and long-term. Countries can reduce many burden of diseases such as stroke, lung cancer, asthma and heart diseases by lowering the levels of air.

Mostly tended to severe health problems from polluted air are people with heart diseases, lung diseases, pregnant women, outdoor workers, children under 14 (their lungs are still developing), and athletes who

exercise actively outdoors. High air pollution levels can be the cause for instantaneous health problems such as damaging cells in breathing system, adding stress to heart and lungs (which causes harder work for organs to supply body with oxygen), and complicates respiratory and cardiovascular illness. Long-term exposure to pollute air can cause development of diseases such as bronchitis, asthma and possibly cancer, fasten aging of lungs and decrease their function (Sacramento Metropolitan Air Quality Management District, 2016).

The damage of air pollution is also considering economic impacts, cutting lives short, increasing medical costs and reducing productivity.

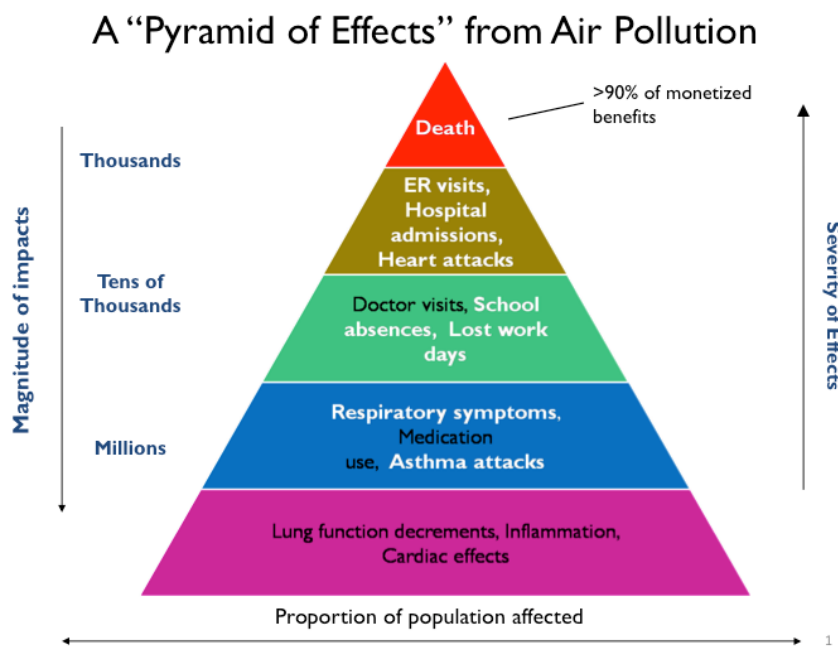


Figure 4 - "Pyramid of Effects" from Air Pollution (EPA-US, 2015)

#### 2.3.4 EXISTING POLICIES ON AIR POLLUTION

##### 2.3.4.1 Introduction

The first international binding instrument for dealing with air pollution problems on the broad regional basis was *The Convention on Long-range Transboundary Air Pollution* (United Nations, 1979), signed in 1979 and it came into force in 1983. The Convention developed international environmental law and created important framework for controlling and reducing air pollution, that damages human health and the environment (United Nations Economic Commission for Europe, 2016). This first Convention dates of the 1960s when the scientists demonstrated the relationship between sulphur emissions in continental Europe and acidification of Scandinavian lakes. From 1972 to 1977, different studies confirmed that air pollutants could travel several thousands of kilometres before deposition and damage occurred. This also brought to mind that cooperation at international level was essential for solving or minimizing problems in what concerns air pollution. The Convention, besides bringing the general principles of international cooperation, also establishes an institutional framework gathering research and policy (United Nations Economic Commission for Europe, 2016).

In last 25 years, in order to decrease the vehicle emissions of greenhouse gases and air pollution, Europe started to sort the policies. For improving energy security and reduce GHG emissions from transport, EU is going to reduce fuel consumption. In 2009, the regulation was established for new passenger cars sold in Europe, to achieve lower average emissions of CO<sub>2</sub>.

Due to existing policies, established along the last decades, the results for air pollution have shown improvements (Eurostat, 2015) and EU Member States reduced exposure to PM by:

- setting up policies at country level;
- reducing the proportion of diesel-engine road vehicles among city-dwellers;
- lowering the average age of the car fleet in general.

The 2005 Thematic Strategy on Air Pollution (TSAP) also settles the measures needed to make the progress.

Later in 2013, the European Commission proposed the new policy for Europe, which sets the goal from 2020 until 2030 to minimize air pollution and its impacts on environment and health. The existing white paper is considering improving air quality for the year 2020 when compared to the base year of 2000 (EEA, 2015).

### 2.3.4.2 Air pollution limits from WHO and EEA

As it is known, the results for air pollution are getting better comparing to last decades, but it is still not satisfactory. The World Health Organization and European Union have set the guidelines for air pollutants (Figure 5). In some cases, the standards given from WHO are stricter than EU limits. These limits are set to minimise health effects and these guidelines are considered to be acceptable and achievable (EEA, 2015).

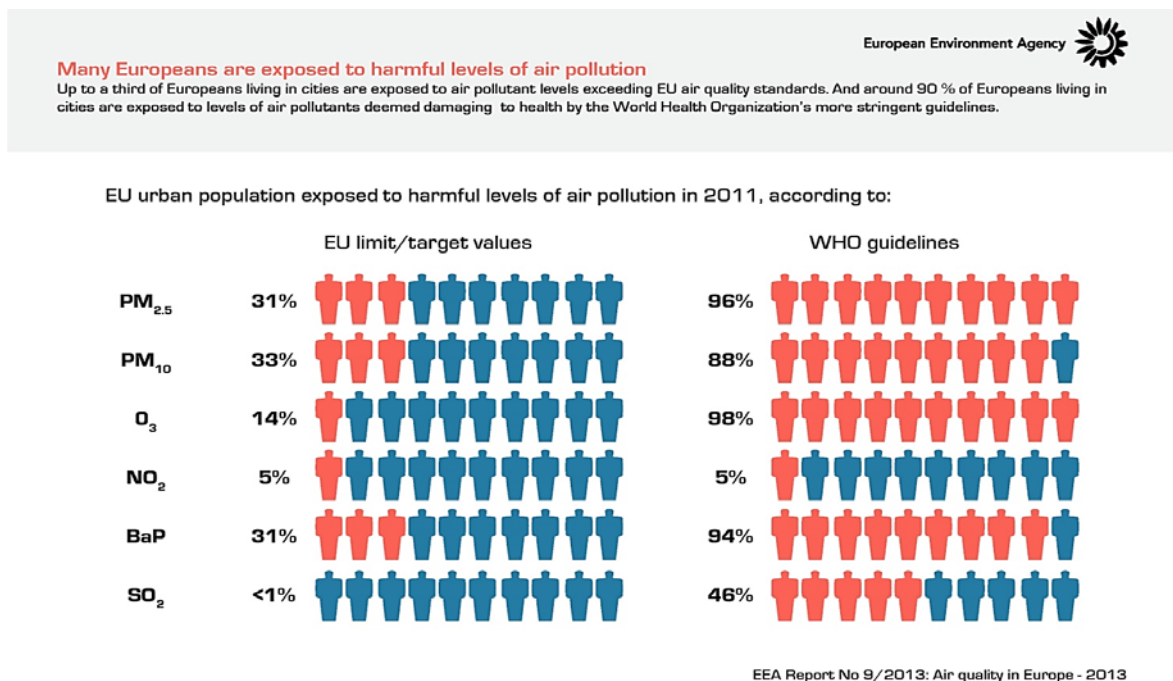


Figure 5 - EEA Report No 9/2013: Air quality in Europe – 2013, the figure shows the population that was being exposed to harmful levels of air in 2011 according to the EU and WHO limits (EEA, 2015)

In the following table (Figure 6), it is shown the air quality standards for NO<sub>2</sub>, set by WHO guidelines and the Ambient Air Quality Directive (EU, 2008) as well. The limits are set for short-term and long-term limit values to protect the human health (EEA, 2015).

Averaging period	EU Air Quality Directive		WHO AQG
	Objective and legal nature	Concentration	
1 hour	Human health limit value	200 µg/m <sup>3</sup> , not to be exceeded on more than 18 hours per year	200 µg/m <sup>3</sup>
Calendar year	Human health limit value	40 µg/m <sup>3</sup>	40 µg/m <sup>3</sup>
1 hour	Alert (*) threshold	400 µg/m <sup>3</sup>	
Calendar year	Vegetation critical level	30 µg/m <sup>3</sup> (b)	

**Notes:** (\*) To be measured over 3 consecutive hours at locations representative of air quality over at least 100 km<sup>2</sup> or an entire zone or agglomeration, whichever is the smaller.

(b) As NO<sub>x</sub>, expressed as µg NO<sub>x</sub>/m<sup>3</sup>.

**Source:** EU, 2008; WHO, 2006a.

Figure 6 - Air quality standards for NO<sub>2</sub> and NO<sub>X</sub> as set out in the EU Ambient Air Quality Directive and WHO AQG (EEA, 2015)

Figure 7 shows the European standards for air quality and WHO guidelines for Ozone (O<sub>3</sub>). The table shows a maximum daily 8 hours mean threshold needed for health protection. According to EU, from 1 January 2010, the goal is not to exceed that limit in more than 25 days per year at the monitoring stations. When the alert threshold is exceeded for more than three consecutive hours, the short-term action plan is required according to specific provisions that are established by Air Quality Directive (EU, 2008) (EEA, 2015).

Averaging period	EU Air Quality Directive		WHO AQG
	Objective and legal nature	Concentration	
Maximum daily 8-hour mean	Human health target value	120 µg/m <sup>3</sup> , not to be exceeded on more than 25 days per year averaged over 3 years	100 µg/m <sup>3</sup>
AOT40 accumulated over May to July	Vegetation target value	18 000 (µg/m <sup>3</sup> ).h averaged over 5 years	
Maximum daily 8-hour mean	Human health long-term objective	120 µg/m <sup>3</sup>	
AOT40 accumulated over May to July	Vegetation long-term objective	6 000 (µg/m <sup>3</sup> ).h	
1 hour	Information threshold	180 µg/m <sup>3</sup>	
1 hour	Alert threshold	240 µg/m <sup>3</sup>	

**Note:** AOT40, accumulated O<sub>3</sub> exposure over a threshold of 40 ppb. It is the sum of the differences between hourly concentrations > 80 µg/m<sup>3</sup> (= 40 ppb) and 80 µg/m<sup>3</sup> accumulated over all hourly values measured between 8.00 and 20.00 Central European Time.

**Source:** EU, 2008; WHO, 2006a; WHO, 2008.

Figure 7 - Air quality standards for O<sub>3</sub> as defined in the EU Ambient Air Quality Directive and WHO AQG (EEA, 2015)

In Figure 8 are the limits, set by the Air Quality Directive for short-term and long-term periods, regarding PM<sub>10</sub> concentrations. For PM<sub>2.5</sub> only the long-term concentrations are set. The Air Quality Guidelines for PM set by WHO are stricter comparing to EU air quality standards. The goal is to achieve the lowest

possible concentrations, as there is no concentration for PM that does not bring harm to human health (EEA, 2015).

Size fraction	Averaging period	EU Air Quality Directive		WHO AQG
		Objective and legal nature and concentration	Comments	
PM <sub>10</sub>	1 day	Limit value: 50 µg/m <sup>3</sup>	Not to be exceeded on more than 35 days per year	50 µg/m <sup>3</sup> (*)
PM <sub>10</sub>	Calendar year	Limit value: 40 µg/m <sup>3</sup>		20 µg/m <sup>3</sup>
PM <sub>2.5</sub>	1 day			25 µg/m <sup>3</sup> (*)
PM <sub>2.5</sub>	Calendar year	Target value: 25 µg/m <sup>3</sup>		10 µg/m <sup>3</sup>
PM <sub>2.5</sub>	Calendar year	Limit value: 25 µg/m <sup>3</sup>	To be met by 1 January 2015 (until then, margin of tolerance)	
PM <sub>2.5</sub>		Exposure concentration obligation (b), 20 µg/m <sup>3</sup>	2015	
PM <sub>2.5</sub>		Exposure reduction target (b), 0–20% reduction in exposure (depending on the average exposure indicator in the reference year) to be met by 2020		

**Notes:** (\*) 99th percentile (3 days/year).  
(b) Based on a three-year average.

**Source:** EU, 2008; WHO, 2006a.

Figure 8 - Air quality limit and target values, and other environmental objectives, for PM10 and PM2.5 as given in the EU Ambient Air Quality Directive and WHO AQGs (EEA, 2015)

Figure 9 presents the European standard for air quality and the guidelines from WHO for SO<sub>2</sub>. The limits are for 1-hour and for the 24-hour average. On the table there is also given an alert threshold and when it is exceeded over three consecutive hours, there is the need to implement an action plan to lower the level of SO<sub>2</sub> (EEA, 2015).

Averaging period	EU Air Quality Directive		WHO AQG
	Objective and legal nature	Concentration	
10 minutes			500 µg/m <sup>3</sup>
1 hour	Human health limit value	350 µg/m <sup>3</sup> , not to be exceeded on more than 24 hours per year	
1 day	Human health limit value	125 µg/m <sup>3</sup> , not to be exceeded on more than 3 days per year	20 µg/m <sup>3</sup>
1 hour	Alert threshold (*)	500 µg/m <sup>3</sup>	
Calendar year	Vegetation critical level	20 µg/m <sup>3</sup>	
Winter (1 October–31 March)	Vegetation critical level	20 µg/m <sup>3</sup>	

**Note:** (\*) To be measured over 3 consecutive hours at locations representative of air quality over at least 100 km<sup>2</sup> or an entire zone or agglomeration, whichever is the smaller.

**Source:** EU, 2008; WHO, 2006a.

Figure 9 - Air quality standards for SO<sub>2</sub> as given in the EU Ambient Air Quality Directive and WHO AQG (EEA, 2015)

### 2.3.5 LATEST DATA ON AIR POLLUTION IN EUROPE

#### Transport emissions of PM2.5, CO, SOx, NMVOC, NOx in EEA member countries.

According to the latest results from the EEA report on Air Quality in Europe (EEA, 2015), there is an evidence that number of pollutants in the air is still high and more work needs to be done to decrease air

pollution, even though, in the transport sector, since 1990, a significant change has been made in reducing air pollutants emissions. During past years, transport related policy actions to reduce air pollution has increased. In the places with high air pollution from transport, are being implemented local and regional air quality management plans.

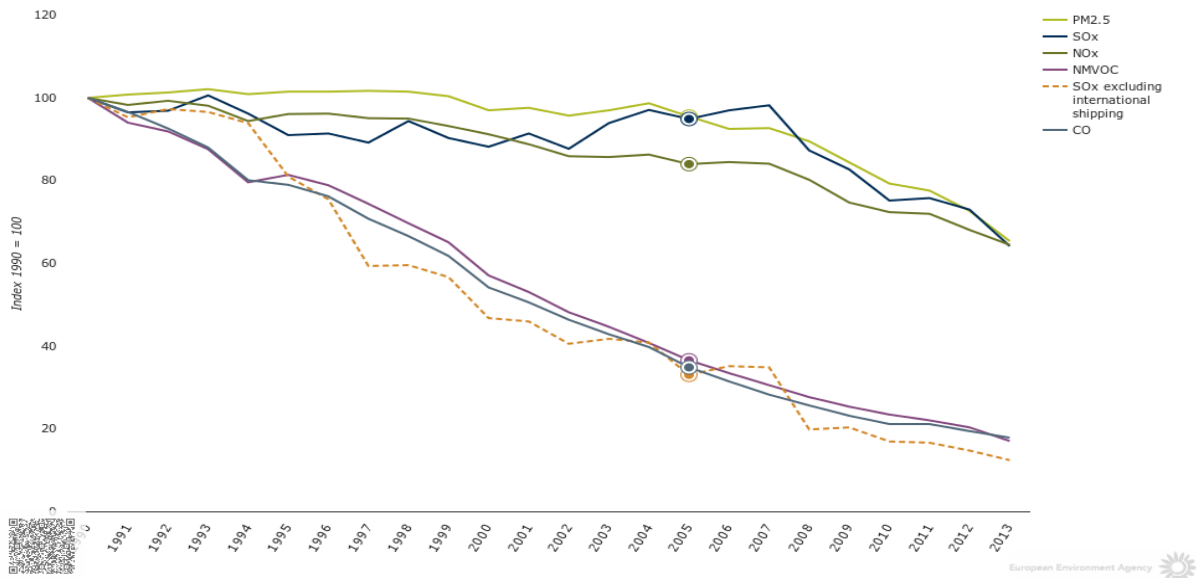


Figure 10 - Trend in emissions of air pollutants from transport (EEA, 2015)

Road transport remains the major contributor for all the main air pollutants. In Figure 10 it is shown that the emissions from transports have significantly decreased during past years. However, the results are still not satisfactory according to the guidelines given from EEA and WHO. The results for the year 2013 year are the following (EEA, 2015):

- PM<sub>2.5</sub> – 65.4
- SO<sub>x</sub> – 64.2
- NO<sub>x</sub> – 64.5
- CO – 17.9

## 2.4 NOISE POLLUTION

### 2.4.1 INTRODUCTION

Noise pollution is unpleasant sound that is causing harm to health and environment. The effect of noise pollution depends on intensity, duration and frequency. Environmental noise is known as one of the biggest environmental problems. It became even a bigger concern with increasing urbanization. The highest contribution to environmental noise in urban areas comes from road, rail and air transport as one can see in Figure 11. According to European Environment Agency, about 75% of Europe's population lives in cities, that are suffering from the pollution and traffic volumes that still on the rise (EEA, 2012).

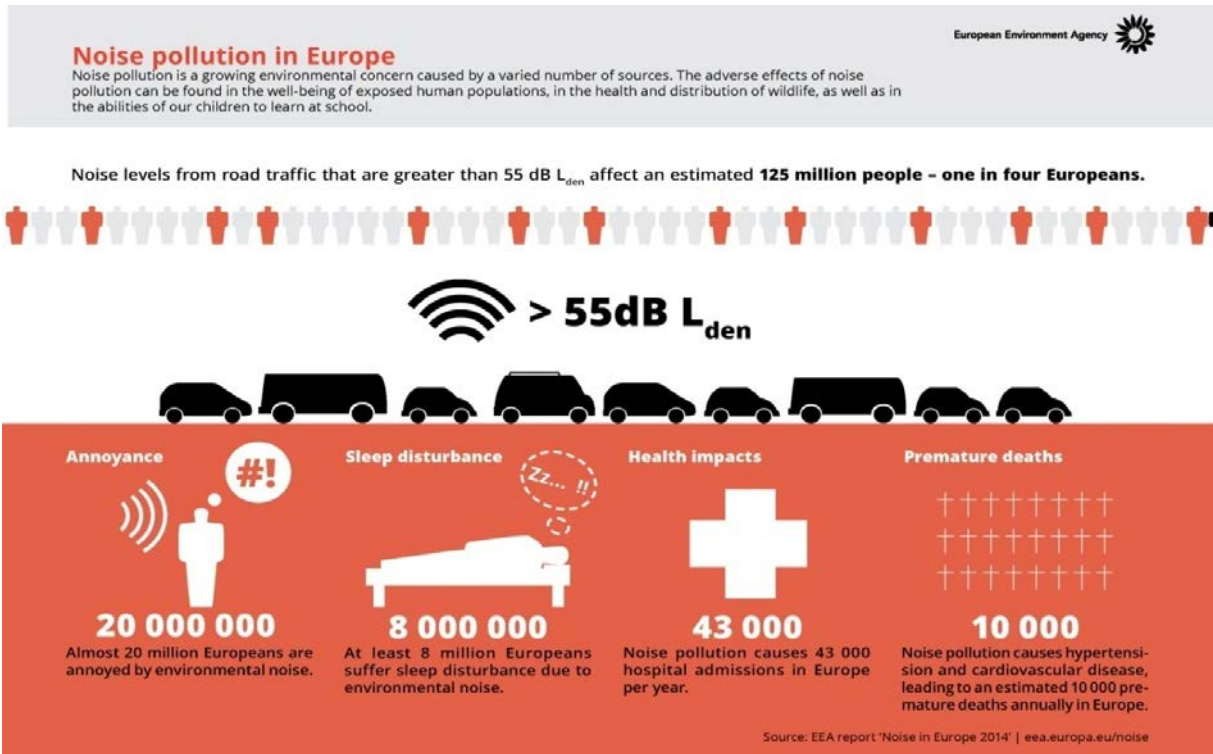


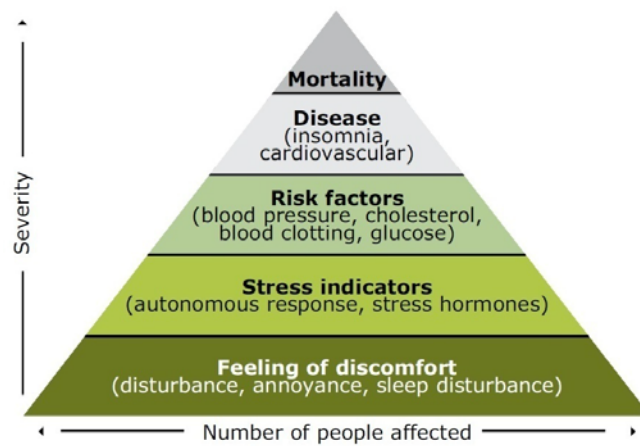
Figure 11 - Noise pollution in Europe (EEA E. E., 2014)

Traffic noise is characterized as noise that is connected to all modes of transportation in all types of infrastructure (streets, roads, railways, planes & airports).

The place and environment that has the influence from noise, especially when it is interacted with other environmental annoyance, such as air pollution, can be thought of the place where the most of the stressors coexist (EEA, 2012). This is why it is important to think of the best solutions, to try to decrease the air pollution and noise, because they bring the major harm for human health and environment.

#### 2.4.2 HEALTH EFFECTS FROM NOISE POLLUTION

In Europe, both inside and outside urban areas, the major source of noise is road traffic (EEA, 2016). Exposure to high levels of noise from road transport has become the major concern as they bring harm to human health and well-being. According to the European Environmental Agency, around 90 million people, who are living in the cities, were exposed to noise levels, coming from the road transport, that were exceeding European standards. Noise pollution can damage eardrum and middle ear and it can affect people, both physiologically and psychologically, bringing disorder to sleep or rest, disturbing study and interfering with communication.



**Source:** Babisch, 2002, based on WHO, 1972.

Figure 12 - Pyramid of noise effects (European Commission, 2015)

As highlighted in Figure 12, effects from noise pollution rise in severity from a simple discomfort until death. They derive from stress, high blood pressure, anger and frustration, lower resistance to diseases and infections, circulatory problems, asthma, colitis, headaches, etc. The main consequences from noise pollution arising from the effects mentioned previously are annoyance, sleep disturbance, cardiovascular disease and the risk of hypertension, effects that can lead to premature death.

According to the data reported in 2011 by the EU countries, around 19.8 million adults are being ‘annoyed’ by noise from road traffic, railways, aircrafts or industry (Figure 13). Almost 8 million adults have sleep disturbance due to nighttime noise pollution (EEA, 2014).

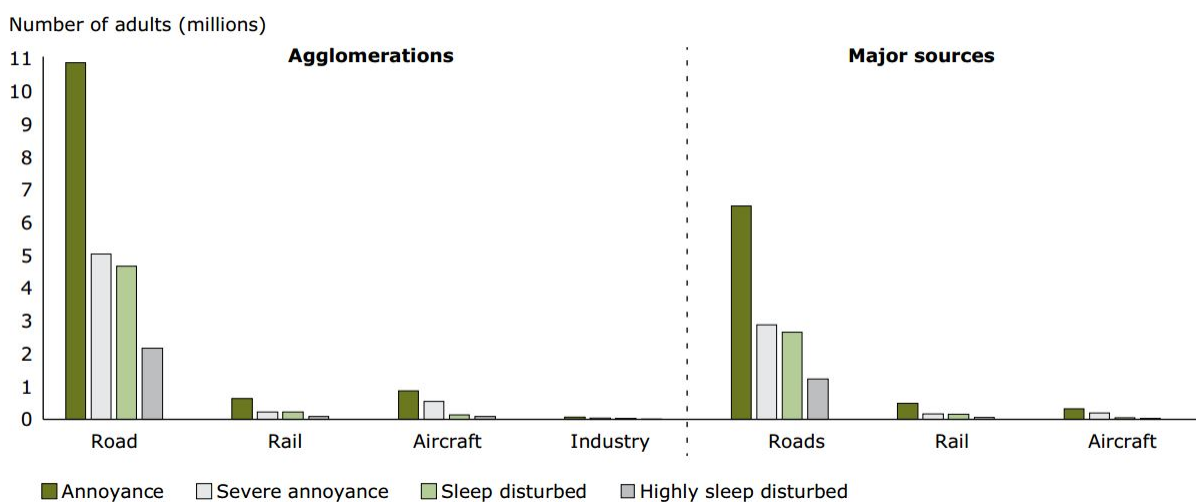


Figure 13 - Estimated number of adults with (severe) annoyance and estimated number of adults that are (highly) sleep disturbed according to noise source and location of the assessment

2.4.3 EXISTING POLICIES ON NOISE POLLUTION

According to European Commission, around 50 million people living in urban areas suffer from excessively high levels of traffic noise at night and for 20 million of them night-time traffic noise actually has a damaging effect on health (Figure 14)(Figure 15). The biggest problem is loss of sleep. The World Health Organization recommends that for a good night's sleep, continuous background noise should stay below 30 decibels and individual noises should not exceed 45 decibels (European Commission, 2015).

Specific environment	Critical health effect	Day: $L_{Aeq}$ (dB(A)) Night: $L_{night}$ (dB(A))	Time base (hours)
<b>Day-time and evening noise</b>			
Outdoor living area	Serious annoyance, daytime and evening	55	16
	Moderate annoyance, daytime and evening	50	16
Dwellings, indoor	Speech intelligibility and moderate annoyance, daytime and evening	35	16
School class rooms, and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class
School playground, outdoor	Annoyance	55	During play
Hospital ward rooms, indoors	Sleep disturbance, daytime and evenings	30	16
Hospital, treatment rooms, indoors	Interference with rest and recovery	a	
<b>Night-time noise</b>			
At the façade, outside	Body movements, awakening, self-reported sleep disturbance	30	During the night

<sup>a</sup> As low as possible.

Figure 14 - Selected values from the WHO Community Noise Guidelines and WHO Night Noise Guidelines (European Commission, 2015)

The Environmental Noise Directive (END) is the legal document from European Union that obligates EU Member States to achieve the action plans to reduce exposure in the cities and also to use common criteria for noise mapping (EEA, 2015).

**Box 1: Noise indicators in the Environmental Noise Directive**

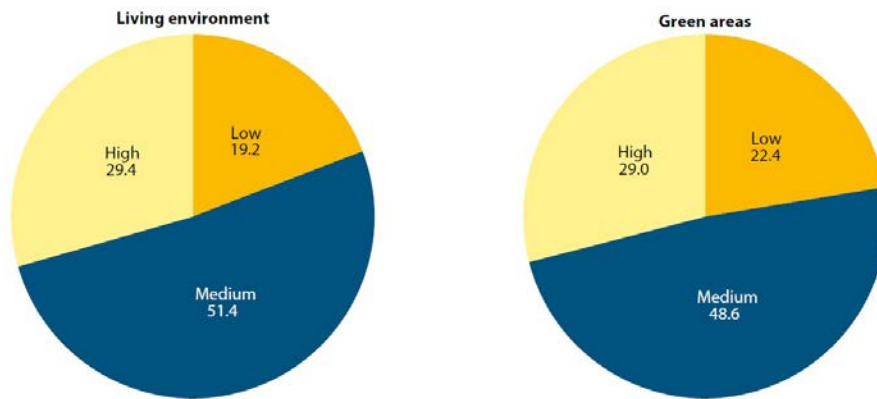
The END requires two main indicators to be applied in the assessment and management of environmental noise.

- The first indicator ( $L_{den}$ ) is the decibel level for day, evening, and night periods and is designed to measure 'annoyance'. The END defines an  $L_{den}$  threshold of 55 dB.
- The second indicator ( $L_{night}$ ) is the decibel level for night periods and is designed to assess sleep disturbance. An  $L_{night}$  threshold of 50 dB is defined.

Figure 15 - Noise indicators in the Environmental Noise Directive (EEA E. E., 2014)

## 2.5 AIR AND NOISE POLLUTION TODAY

Over the last decade, according to European Environment Agency data (EEA, Explaining road transport emissions, 2016), the environmental problems such as air and noise pollution have decreased. However, one out of seven people consider themselves affected by air pollution in 2013 and one out of five people to suffer from noise. In view of these results in average, 20% of EU population declared low satisfaction with their living environment and the availability of green or recreational areas situated near to their areas of residence, 30% expressed high satisfaction, and the other 50% reported medium satisfaction (Figure 16). This result grades personal satisfaction with the living environment with 7.3, in a scale from 0 to 10, and with 7.1 regarding the satisfaction with green areas (Eurostat, 2015).



Source: Eurostat (online data code: ilc\_pw05)

Figure 16 - Satisfaction with living environment and green areas, in percentage, EU-28, 2013 (Eurostat, 2015)

# 3

## STATE OF THE ART REVIEW

### 3.1 INTRODUCTION

The methodology in this dissertation involved three pillars of knowledge: *Air pollution*, *Noise* and their connection with the Quality of citizens' Life, considering their relation with spatial planning and the urban context.

Here, the importance of citizen's well fare and quality of life is highlighted at two levels. First, they are one of the most relevant agents in the prevalence of noise and air pollution in the society; secondly, the population is the most affected by the negative effects of those pollutants, concerning not only their health but also their properties and personal belongings.

Pursuing those purposes, this dissertation follows a methodological plan whose structure is explained in the following point, considering not only the activities that provided the information to complete these document, but also the most relevant findings and an example in the use of those findings to achieve an acceptable environment in terms of less air pollution and lower environmental noise.

### 3.2 METHODOLOGICAL APPROACH

#### 3.2.1 INTRODUCTION

At first, the need for information about air pollution and noise that resulted in the gathering of several documents, reports, and scientific papers, in order to understand the problem, and the present *status quo*.

The next task was to discover and gather all the main measures that can help to reduce air pollution and noise, improving the quality of life of urban citizens. The correct types of mitigation actions are needed to be introduced in order to bring benefits for environment and people's lives and improve quality of life of the inhabitants.

Low-carbon transport strategies are very important for environmental, social and economic targets. These strategies include improving mobility, safety and public health, reducing air and noise pollution, reducing traffic, and parking blockage.

According to technical report about sustainable development benefits of low-carbon transport measures, there are highlighted some key benefits related to changing transport system (Lah, 2015):

- Access and mobility, that is essential for both, business and individuals. It can improve travel options including cycling, walking, private and public transport, by creating more effective and short travel distances.

- Air quality and noise pollution, which is major problem nowadays for human health and environment. It causes diseases and health problems, such as loss of hearing, heart disease, and sleep disturbance and sometimes there is a connection with premature death.
- Direct and indirect employment and economic impacts related with effects of sustainable transport, improve the access to jobs and markets and often this bring the attractiveness to people to do business in particular cities with good accessibility.
- Significant improvement in public health by active transport such as cycling and walking. Active transport leads to healthier lifestyle and is giving better results for health problems such as diabetes.
- Road safety is one of the major objectives for improving road transport. Annually huge number of people are victims of road accidents, causing death or serious injuries.

These types of different mitigation actions will influence to bring different benefits and impacts for sustainable development and better quality of life.

The way residents rate highly the benefits from living in the area with green space, it should be taken into consideration. Having connection with the nature is crucial element for quality of life. (Cella, 1994)

Urban green spaces have diverse functions, such as stabilization and filtration of the local climate, reduction urban air temperature, noise debilitation, and it has physical and psychological benefits. Except this positive description, urban green spaces give opportunity to people to have sporty and active life and do it while being connected to nature. Having urban recreation area in the neighbourhood helps residents to maintain social communication as well (Madureira, Nunes, Oliveira, Cormier, & Madureira, 2014).

As so, the methodology scheme presented in Figure 17 – Methodology scheme for the dissertation

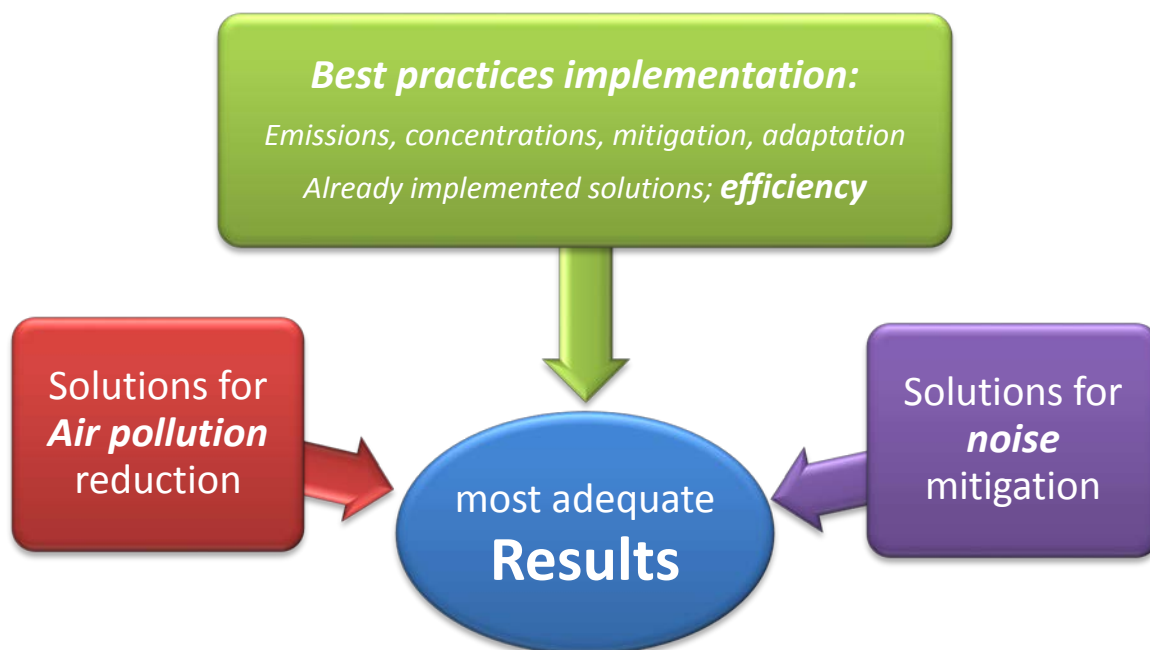


Figure 17 - Methodological scheme of the dissertation

The solutions that are provided in the dissertation, were chosen in a way to create the given structure of methodology. Some of the methods are samples from the cities that already started mitigation actions.

Some implementation are the results from experimental methods done by computer programmes or in the build-up areas.

After defining the meaning of air pollution and noise and the harm that they bring for human health, environment and nature, it was important to find the mitigation actions that can provide minimization of them. For this, different articles, books and reports were analysed in order to gather information on what can be done and what was already done for mitigation actions.

The used material was chosen in a way that can be used for reducing air pollution and noise that comes from traffic. The main strategy was to gather useful information for policy makers and citizens in order to define and explain the problem and show the ways to deal with it.

The gathered information was analysed and divided in two main chapters, solutions for air pollution and solutions for noise. Some of them can be implemented in the city centres, and some can be applied around or outside the city, depending on the scale of their efficiency and characterisations of the city.

There are some difficulties to implement different solutions in city centres, due to a variety of reasons, such as lack of the space, the existence of cultural heritage. This does not give opportunity to change main structures in order to implement solutions that require bigger space.

One should also mention that there is a large body of knowledge, in each of research fields, but the conjugated effect of those solutions is still scarce.

The gathered information should be analysed and discussed, in order to use it in the most appropriate manner in the future works and implementations in the cities and urban areas, in order to provide a better quality of life and well-being of inhabitants.

### **3.3 DIFFERENT APPROACHES ON MITIGATION MEASURES**

#### **3.3.1 INTRODUCTION**

There are several ways to reduce traffic emissions whether it is inside or around the city. Some can be more efficient but, if the mitigation actions are implemented not in the correct way it may not only slower the process of reducing pollution, but also prevent improvements. In this chapter, different implementations are discussed and suggested in which parts of the urban areas it is best to use them.

In this dissertation, also two main characteristics can be taken by which the implementations will be divided: city centers and areas around the city. Different methods need particular scales in order to have proper use and gain good results.

The given work gives examples and methodologies from cities or from experiments, that proved can have effect on decreasing air pollution and noise. Mainly the methods are connected with vegetation, public transport, policies, materials, pricing, urban furniture and activities that are held as an experiment in some cities.

Considering air and noise pollution that are coming from transportation there can be found different key ways how to deal and reduce traffic in the cities with dissimilar characterization. There are many cities in Europe that started dealing with air and noise pollution and according to type of the city divergent resolution are possible to be reviewed.

This part of dissertation work will introduce different mitigation actions that can be implemented in order to improve quality of life with reducing air pollution and noise. Different articles were analyzed in order to gain a knowledge and provide information on how to reduce traffic, air pollution and noise in the cities and urban environment.

### 3.3.2 TRAFFIC REDUCTION

The share of traffic as one of the main contributors to air pollution and noise is very significant. Traffic is one of the major sources of environmental pollution, and related harmful effects for human health, including increased mortality rates, as mentioned previously. The exposure to traffic related problems is a matter of apprehension and actions to reduce traffic in the cities should be a primary concern of municipal authorities, in order to bring positive changes for population. Figure 18 shows a summary of some examples regarding traffic reduction measures reported in analysed studies.

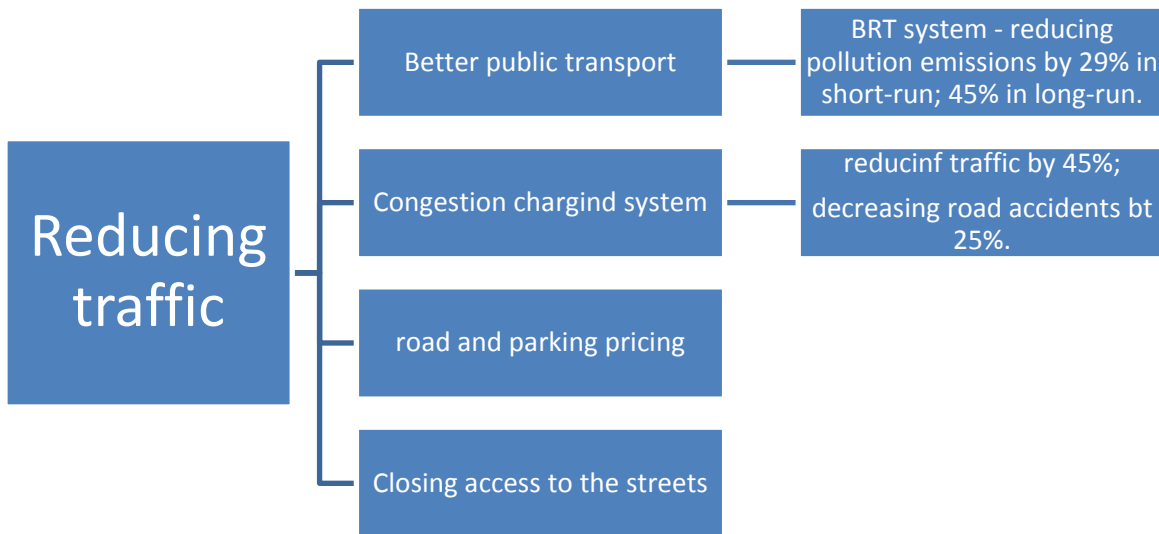


Figure 18 - Measures for traffic reduction

### 3.3.3 AIR POLLUTION MITIGATION

The analysis, regarding mitigation of air pollution, involved the consideration of some articles, which stated the most typical approaches used to improve air quality, including the control of air pollutants concentration, the intensity of emissions and pathways of source-receivers. These approaches are related with the main methods to implement for air pollution mitigation. In Figure 19 are highlighted the main methods to reduce air pollution, including a collection of mitigation actions.

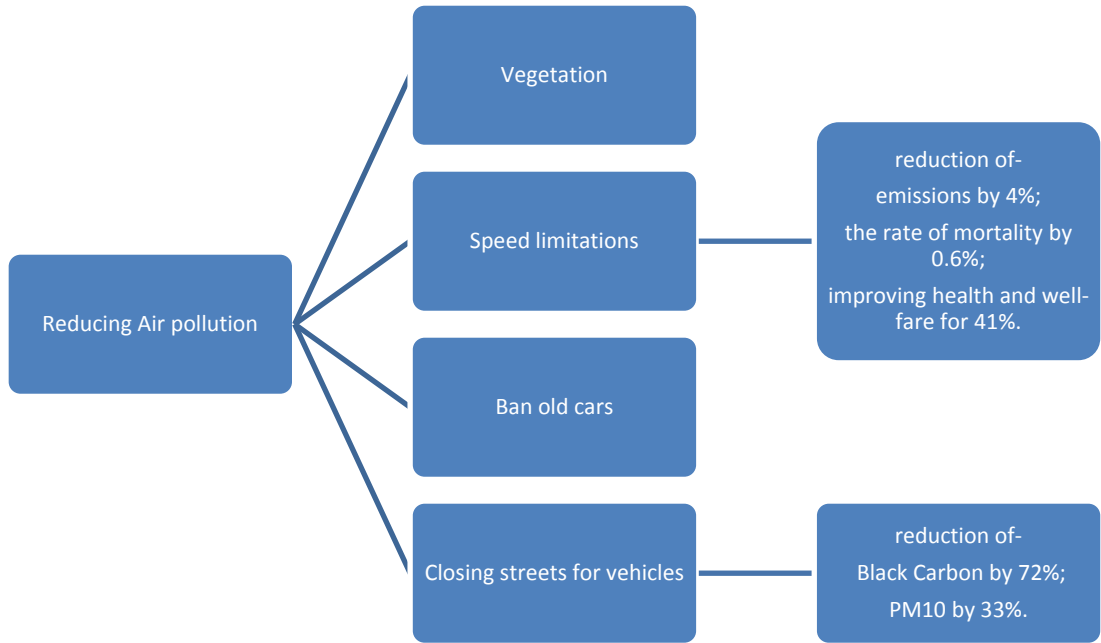


Figure 19 - Measures for air pollution mitigation

### 3.3.4 NOISE MITIGATION

Mitigation actions for road traffic noise can be divided in three main methodologies: reducing noise from the source, reducing noise between the source and the receiver and reduce noise on the receiver side. Some of these technological measures are discussed in this dissertation work, considering their contribution to reduce noise in urban areas and in cities, and shown in Figure 20:

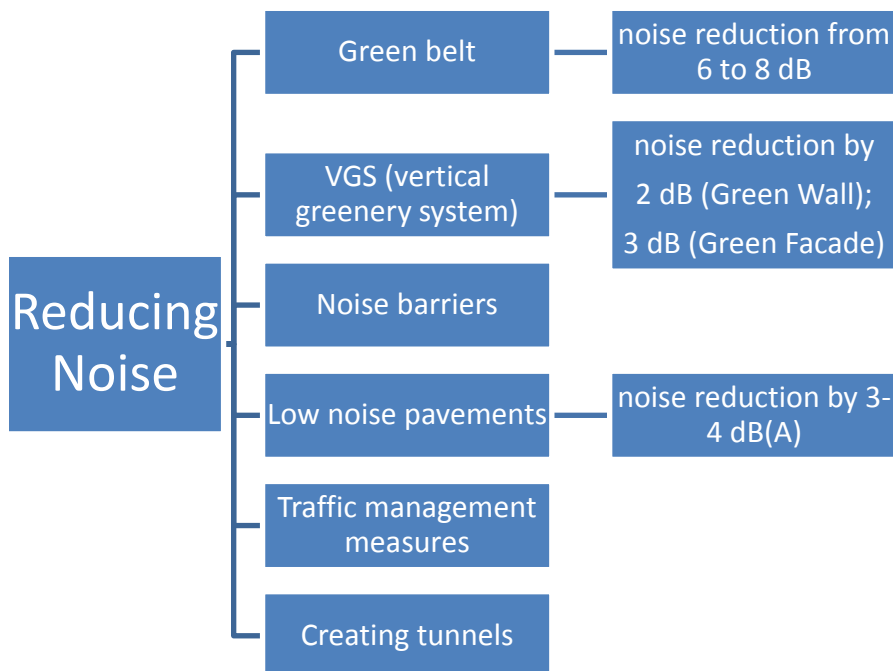


Figure 20 - Measures for noise mitigation

### 3.4 BEST PRACTICES RESEARCH

#### 3.4.1 INTRODUCTION

During this dissertation, research was conducted not only with respect with present and past European projects that involved mitigation measures on noise and air pollution, but also related with implementation projects whose results were reported in scientific journals.

In the following parts, it is possible to find a summary of that research.

#### 3.4.2 INTERNATIONAL PROJECTS FOR AIR POLLUTION AND NOISE MITIGATION

Except the mitigation actions for air pollution and noise that are discussed in this work, there are different projects worldwide, such as:

- SMILE (Sustainable Mobility Initiatives for Local Environment) (Guidelines for European Noise Abatement, 2014);
- HOSANNA (HOListic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means) (Chalmers, 2007-2013);
- STATUS OF RESEARCH ON POTENTIAL MITIGATION CONCEPTS TO REDUCE EXPOSURE TO NEARBY TRAFFIC POLLUTION (Air Resources Board, 2013);
- Traffic noise reduction in Europe (den Boer & Schrotten, 2007);
- Joaquin (The Joaquin Decision Support Tool) (The Joaquin, 2016);
- Manual Tecnico para Elaboracao de Planos Municipais de Reducao de Ruido ( (Oliveira de Carvalho & Rocha, 2008).

These are the main projects that are used in this section to introduce the mitigation action programs, which are suggesting the possible solutions for reducing air pollution and noise coming from traffic.

The methods are discussed and gathered in Table 1:

Table 1 - Gathered implementations from different projects

<u>MITIGATION METHOD</u>		<b>REDUCTION</b>	<b>COSTS AND BENEFITS</b>
<b><u>Innovative barrier</u></b>	Low-height barrier	3 –12 dB(A) for an urban road and 9–15 dB(A) for a tramway	Improves appearance; Contributes to pedestrian and cyclist security
	Light vegetated barrier	Up to 5 dB(A) below a road traffic bridge, up to 15 dB(A) below a tramway bridge	Improves appearance; Contributes to biodiversity
	Earth berms with strongly non-flat surfaces	Up to 5 dB(A) compared with a smooth trapezoidal berm at a distance of 1–50 m	Improves appearance; Less graffiti than for a barrier ; Contributes to biodiversity

<b><u>MITIGATION METHOD</u></b>		<b>REDUCTION</b>	<b>COSTS AND BENEFITS</b>
<b><u>Trees, shrubs, and bushes</u></b>	Trees in street canyons and courtyards	No more than 2 dB(A) for close positioning of trees in the street	Fully green solution (e.g., CO <sub>2</sub> uptake, increases biodiversity); Improves appearance
	Tree belts (multiple rows of trees)	Up to 6 dB(A) at a distance of 50 m for a 15-m-deep tree belt; up to 10 dB(A) for a 30-m-deep belt	Fully green solution (e.g., CO <sub>2</sub> uptake, increases biodiversity); Improves appearance; Air pollution reduction
	Trees behind barriers	Up to 5 dB(A) at a distance of 100 m in strong downwinds near highways	Strongly reduces negative visual impact of noise walls
<b><u>Vegetated facades and roofs</u></b>	Vegetated roadside facades	2–3 dB(A) at a height of 1.5–4 m on the facade	Improves appearance; Reduces air pollution
	Vegetated facades in urban squares	3 dB(A) at a height of 1.5 m throughout the square	Improves appearance; Improves thermal insulation of buildings
	Vegetated roofs	2.5 dB(A) for flat roofs and 8 dB(A) for angled roofs	Improves appearance; Reduces heat loss and incoming heat flux into the building; Ameliorates storm water runoff; Low costs of installatio
<b><u>Reducing traffic density</u></b>	Promoting public transport		Stabilising traffic flows; Enlarging the public transport system; Promoting environmentally friendly means of transport, e.g. walking and cycling
	encouraging cycling and walking		
	traffic management and parking		
<b><u>Speed reduction / traffic calming measures</u></b>			Reducing excessive driving speeds; Designating 30 km/h zones; Designating traffic-calmed (business) zones
<b><u>Renewal of public transport and (heavy) goods vehicles</u></b>			Introducing low-noise buses and trams; Promoting low-noise (heavy) goods vehicles

<b><u>MITIGATION METHOD</u></b>		<b>REDUCTION</b>	<b>COSTS AND BENEFITS</b>
<b><u>Changing the road surface</u></b>	improvements to roads		Use of low-noise road surfaces
<b><u>Urban planning</u></b>			Reducing / avoiding traffic by decentralizing local amenities into sub-centres of settlement
			Interposing less sensitive uses between the noise source and sensitive uses

### 3.4.3 REDUCING TRAFFIC

As the main reason for air pollution and noise is traffic, it will be correct to find different ways to reduce number of private vehicles in the cities. Reduction of cars will decrease traffic and automatically improve air quality. But as long as transport plays essential role in peoples' lives, the actions should be chosen correctly in order not to harm and delay peoples' needs and at the same time to provide healthy and clean environment.

Mitigation of private cars require improvements in public transport, good management, cycling and walking networks.

Transportation blockage is large and urgent problem in many cities and urban areas. Charging for congestion focuses on charging drivers for using vehicles at busy times and locations to reduce travel times in case to improve air quality and decrease greenhouse gas emissions (Ed Pike, 2010).

Figure 21 shows a good example, with the same number of people, accommodated in different type of vehicles. The experiment shows 200 people using private vehicles, in three buses, using the light train, using bikes and just seating in the street without any vehicle. These images are good example to highlight the difference between the land occupation by road traffic, public transportation and soft modes of transportation that can create the conditions to change or mix uses in city centers, fomenting the reduction of private vehicles in the heart of the cities.

The congestion charging system was first developed in Singapore in 1975. It brought the good result almost immediately, with reducing traffic by 45% and decreasing road accidents by 25%. This system also increased the public transport use and improved infrastructure capacity, safety and air quality. Nowadays the 65% of citizens in Singapore are using public transport. Later in 1998 the Area License System (ALS) was replaced by Electronic Road Pricing (ERP) program, which is using the road space at its highest level and maintaining optional speeds, it is being reviewed quarterly. After bringing into use the renewed system in 1998, it decreased traffic levels for more 15%, and reduced CO<sub>2</sub> emissions and particulate matter (Danish Architecture Centre, 2014).

Congestion charging can reduce CO<sub>2</sub> emissions, makes people more active in their everyday life and provides safer and more liveable environment.

In recent years' road pricing has become broader. It provides the maintenance of public motorways, finance and environment. In European Union there are three different groups of countries according to their road pricing experience (Gutiérrez, Condeço-Melhorado, Martín, & Román, 2013):

- The first group includes the countries that are charging tolls in order to finance the construction and maintenance of motorways. These are countries such as France and Italy.
- The second group contains the countries that have fixed fees for heavy vehicles, countries such as Sweden, Denmark, Belgium, Netherlands and Luxembourg.
- The third group of countries is distance-based road user toll for heavy goods vehicles, it means that the pricing is based on the distance, and countries with this type of pricing are Austria, Germany and Czech Republic.



Figure 21 - Same Number of People Using Different Vehicles (The Commuter Toolkit, s.d.)

The following method that will be discussed is already in use in many cities. It considers pricing on parking spaces mainly in the city centers. Putting price on parking spaces may give a chance to driver to rethink of taking a car in the city or leave it and use public transport. Paying for parking space is connected with economy, and it can be considered as the major factor for citizens. This factor is continued by lack of the parking spaces in the city centers mostly that is connected with losing time while searching for place. So this point can be considered as one of the good methods to reduce number of citizens who use private vehicle.

Physical inactivity is one of the major problems for public health in the most of the regions of the world. Development of active transport, such as walking and cycling can be very helpful for physical activity and positive environmental effects (WHO Regional Office for Europe, 2014).

Also to reduce air and noise pollution in the cities and to raise physical activity in citizens is to close the access in the streets for cars in the central areas and make it accessible only for pedestrians. On one hand it may be difficult in the beginning, as it will change a structure of how transportation works in the city, but after a while people will get used to it.

Depending on different countries there are several ways to use this method. In some cities certain streets are closed for vehicles 24/7. In other cities they are opened for vehicles on weekends and on working days only after 20:00. Most of the times these are the streets, in different countries, that are most popular for the shopping centers and restaurant, and is mostly visited by tourists.

While in some countries and cities government is fighting against forbidden old cars, worldwide the traditions are made for car free days, for example 22 September is now officially known as day when everyone is offered to leave their vehicles at home and use bicycle or simply move by foot. The main goal is to show ‘car addicted’ people that in some cases it is faster to move by foot or bicycle (Figure 22).



Figure 22 - World Car Free Day

Reducing use of private vehicles automatically means providing better public transport that will work effectively. BRT system is an innovative, high capacity and lower cost public transit solution, created for improving urban mobility. This system is using mostly specialized vehicles on roadways in order to provide quick and effective transport for passengers in different destinations. It helps to reduce traffic (National BRT institute, n.d.).

BRT system contains similar features as a light rail or metro system and these features provide the system to be much more reliable and fast, than regular bus services. This system is able to avoid traffic

or other causes of delay that normally makes regular bus services slow (The Institute for Transportation and Development Policy, n.d.).

The other benefits from BRT system are that it is reducing traffic congestion, road and parking cost savings, improved mobility options for non-drivers, reduced pollution and increased safety. In the short-run BRT is able to reduce pollution emissions by 29% and over the long-run about 45% (Hossain & Kennedy, 2008).

As mostly the air and noise pollution is caused by human activities, European Environmental Agency has made an article with the guideline on how each person can help individually to reduce pollution in everyday life activities. These are the daily tips for people who would like to help to reduce air pollution and protect environment (EEA, 2014):

- Take public transport or carpool!

The first tip aims to help people to realize that the one vehicle is better to be used fully, rather than by single driver. It may be useful for longer journeys as well. Also using public transport may be helpful for reducing ozone pollution and CO<sub>2</sub> emissions (EEA, 2014).

- Walk or use the bike!

The main pollutions in Europe come from transport emissions. 45% of ozone and 38% of particulate matter are the cause of transport. The average of the distance that private car users ride is 2 km. Therefore the second tip is to reduce car use and start riding a bicycle or start walking. These activities will not only help to reduce pollution, but also it will help people to become more physically active, that will lead to healthier life (EEA, 2014).

- If you have to use your car...!

When the person is using a car there can be different small details that separately will make slight change but in general it can be very efficient. Here are some daily tips that person can consider in everyday life while using private vehicle. Firstly, it is important to check the right tyre pressure, in case if it is down by 0.5 bars, it means that the car will use 5% more fuel that will cause more pollution. Secondly, while driver is using air conditioner, it is causing the consumption of fuel by 30%, while when air conditioner is turned off and the air comes from the open windows, the consumption is increased only by 5% (EEA, 2014).

Many drivers before starting to drive turn their cars on in order to warm them up. This leads to consuming up to 50% more fuel, while when the driving is starting immediately without warming up, the temperature reaches working degree quicker. And by the end, the tip is for people who are planning on buying the car. Environment-friendly car will cause less pollution and it will use less fuel (EEA, 2014).

### **3.5 REDUCING AIR POLLUTION**

There are several different methods that can be used to reduce air pollution in the cities and particularly in the city centres. This part of the dissertation represents the practices implemented in different countries, cities and urban areas, in order to decrease the air pollution (Table 2).

The following table shows the methods that were discussed in this part of the work in order to investigate what kind of implementations can be useful for air pollution mitigation:

The table presents the name of the authors who worked on the subject, and the dates their research was published. The aim of the table is to show shortly what kind of ways were used in order to reduce air pollution, and in some of the cases the exact results are shown (where they were given).

Around the world the majority of polluted air comes from vehicular emissions, as a result for being exposed to this pollution it brings harms health of the inhabitants of the polluted area and also the built infrastructure. In order to improve the quality of air there are three main approaches outlined:

- 1. Controlling the quantity of pollution;
- 2. Controlling the emission intensity;
- 3. Controlling source-receptor pathways.

Each of these three methods can lead to improved air pollution. The number of inhabitants in the cities are increasing nowadays, and the importance of improving air quality is getting more urgent, because increased number of cars brings more pollution. But taking out the vehicles from the urban areas in order to decrease air pollution is not an easy achievable solution. That is why starting implementing passive methods to improve air quality is good option to be considered (Gallagher, et al., 2015).

The major concern of the authors in the given study was to know how built environment can work to alter natural dispersion patterns in order to improve air quality for inhabitants nearby. Mainly the methods they used included trees and vegetation, some objects that can be used as a noise barrier, low boundary walls and parked cars (Figure 23). Experimental studies have provided an understanding of the potential for these barriers to improve air quality (Gallagher, et al., 2015).

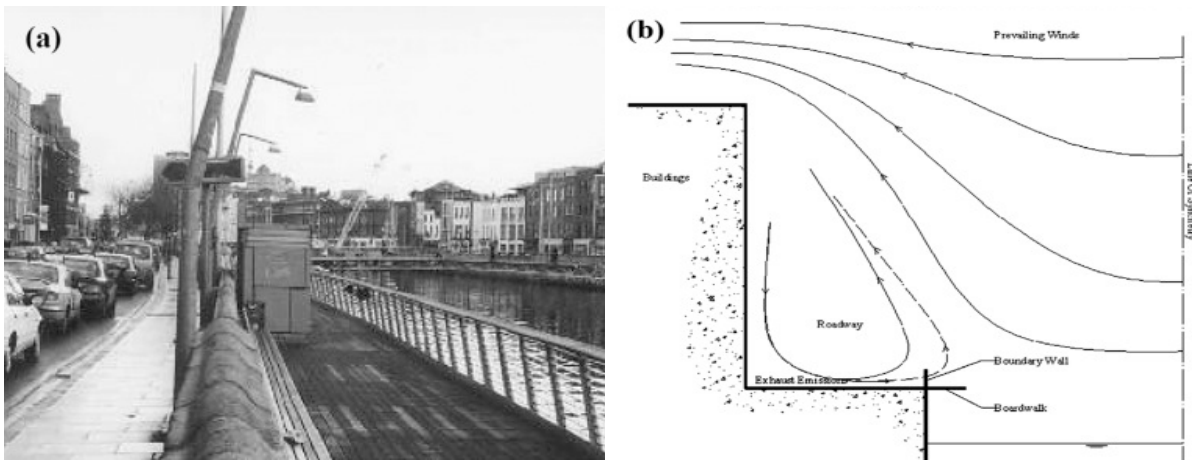


Figure 23 - (a) Boardwalk case study in Dublin, Ireland and (b) air flow profile in street canyon model with boardwalks LBW in perpendicular winds (Gallagher, et al., 2015)

Table 2 - Reducing air pollution

Title	Author	Year	Context (reason for this study)	Data	Case study/ sample size	Country	Which were the problems	Which were the measures implemented	Efficiency/success		Assessment method
									Air pollution	Noise	
<b>AIR</b>											
Impact of local traffic exclusion on near-road air quality: Findings from the New York City "Summer Streets" campaign	Thomas H. Whitlow, Andrew Hall, K. Max Zhang, Juan Anguita	24/fev/11	to promote clean air and good health through exercise	city level, central street	11 km	New York City, United States	increased risks of adverse health effects in populations living, working or going to school near large roadways	closing street to vehicular traffic between 7.00am and 1.00pm for 6.9 miles between the Brooklyn Bridge and Central Park	Both fine and UFP, spike in response to traffic conditions, are enriched with smaller size fractions to varying degrees		
Improving local air quality in cities: to tree or no to tree?	Peter E. J. Vos, Bino Maiheu, Jean Vankrkom, Stijn Janssen	19/out/12	avoiding wrong vegetation in order to keep good air quality	local street level, roadside	street, roadside	Belgium, the Netherlands	wrong way to avoid local air pollution	focus on multiple and traffic related pollutants, different types of vegetation, focus on building geometry and study various real life geometries	more correct way how to direct local vegetation in order to improve air quality		ENVI-met
Evaluation of the impact of transportation changes on air quality	G. Titos, H. Lyamani, L. Drinovec, F. G. Olmo, G. Mocnik, L. Alados-Arboledas	16.05.2015	Traffic emissions are of particular concern in urban areas and their surroundings since traffic-related pollutants have been associated with overall mortality increase.		2 central streets (in which conditions, people, vehicles...)	Spain, Slovenia	air quality, high level of black carbon in air	closing streets to private traffic, renewal of the bus fleet, re-organizing of the public transportation	benefit air quality		
Air pollution impacts of speed limitation measures in large cities: The need for improving traffic data in a metropolitan area	José M. Baldasano, María Gonçalves, Albert Soret, Pedro Jiménez-Guerrero	ago/10	the large impacts on health caused by the exposure to air pollution	city level	motorways in a large city	Spain	Assessing the effects of air quality management strategies in urban areas	comparison of 2008 with 2007 after introducing speed limitation	reducing emission for 4-11%		
Air quality effects of an urban highway speed limit reduction	Marieke B.A. Dijkema, Saskia C. van der Zee, Bert Brunekreef, Rob T. van Strien	dez/08	a lowering of the maximum speed limit from 100 to 80 kph	city level, highway	Daily mean concentrations were compared with measured concentrations in the prior year	the Netherlands		speed limit intervention	PM <sub>10</sub> concentrations has decreased by 2.20 µg m <sup>-3</sup> , PM <sub>1</sub> 0.42 µg m <sup>-3</sup> and Black Smoke 3.57 µg m <sup>-3</sup>		monitoring the intervention area
Factors influencing PM10 emissions from road pavement wear	Mats Gustafsson, Goran Blomqvist, Anders Gudmundsson, Andreas Dahl, Per Jonsson, Erik Swietlicki	fev/08	studded tyres	circular road simulator	three different sets of measurement						
Passive methods for improving air quality in the built environment	R. W. Balday, C. Fuller, P. Kumar, L. Gill	ago/15	built environment work to improve air quality for nearby population'			Dublin, Ireland	air pollution, noise	trees and vegetation, low boundary walks and parked cars	potential to reduce air pollution		
The impact of an urban park on air pollution and noise levels in the Mediterranean city of Tel-Aviv, Israel	Pninit Cohen, Oded Potchter, Izhak Schnell	13.08.2014	aggravated microclimate, thermal discomfort, deteriorated air quality and increased noise levels,	urban parks with more than... m2 or far than ... m from the street		Israel	deteriorated air quality & noise	experimenting from inside the green areas	Urban parks can reduce NOx, CO, and PM10 levels	Urban parks can reduce noise by -5 dB(A)	experimenting from inside the green spaces and urban parks



The analysis showed that the passive barrier such as low boundary walls, trees and vegetation, noise barriers and parked cars can protect inhabitants' health and reduce air pollution concentrations on the local scale, and it depends on the geometry of the environment and meteorological conditions (Gallagher, et al., 2015).

Developing design guidelines is an important next stage in promoting passive methods for reducing air pollution and ensuring their integration into future planning strategies. In addition, developing channels of communication with urban planners will enhance the development and uptake of design guidelines to improve air quality in the built environment. The results from each of the barrier studies provide an evidence base that they have the potential to alter pollutant transport and dispersion patterns that their effectiveness is dependent on local geometrical and meteorological conditions. The future of these methods for improving urban air quality is dependent on matching and balancing these factors (Gallagher, et al., 2015).

Trees and vegetation are one of the many small elements that present passive methods for removing air pollutants and improving the local air quality. The benefits from trees to local air quality can be promoted by systematic green space planning (Vos, Maiheu, Vankerkom, & Janssen, 2013). Considering the botanical, spatial and structural aspects, it is possible to integrate development processes, that aim to maximize the benefits and to encompass the air cleansing function and on the other hand minimize the negative impacts of urban trees. The trees should be planted in heavily polluted areas in order to improve air quality (Jim & Chen, 2007).

Trees, and in general green space, can eliminate air pollution in the atmosphere through dry deposition. Pollutants are transported and destroyed through the surface of plants (Yafei Wang, 2015). Details, such as tree parameters (crown height, leaf density, tree height and spacing), meteorological conditions and streets geometry, can have a big impact on pollution as well. Trees and vegetation offer many benefits to the urban environment and urban planners need to take into account the impact of trees on pollutant dispersion (Gallagher, et al., 2015).

According to the result of the studies about "noise and well-being in urban residential environments", it shows that the existence of green areas in the city brings less affect to the health of residents and their well-being (Gidlof-Gunnarsson & Ohrstrom, 2007). The neighbourhood quality is increasing satisfaction due to green spaces around it. The studies show that residents with "better" accessibility to green areas show less stress-relates psychosocial symptoms, than the ones with "poorer" availability to them. Having green areas nearby, gives residents the chance to escape from stress and noise exposure. Parks are normally related with the longing to relax, rest and listen to the sound of nature.

Except for being a place to rest, having green spaces nearby the living area, motivates residents to use it as a place to exercise. Living physically healthy life by itself brings healthiness to people and increases their quality of well-being. The studies also show that the distance from the apartments to the green areas is very important and it can be one of the major motivator for residents to use it (Gidlof-Gunnarsson & Ohrstrom, 2007). All these knowledge leads to the thought that the recreation areas are very important in everyday life for residents and for better quality of life and that they should be located near living areas.

Vegetation is thought to be mostly very effective solution to deal with air pollution, but different authors are trying to show that in case of incorrect mitigation, it can bring harm instead of bringing benefits (Vos, Maiheu, Vankerkom, & Janssen, 2013).

Some authors are doubting that vegetation is not always the best solution for improving air quality. By modelling a variety of real-life examples, the authors show that local roadside urban vegetation, in some

cases, leads to increased pollutant concentrations. They explain it with the idea that trees reduce the ventilation in the streets. With this, authors argue that urban vegetation is not always viable solution for improving local air quality (Vos, Maiheu, Vankerkom, & Janssen, 2013).

The goal is to investigate different parameters such as building geometry, pollutant type, wind conditions, vegetation type, size position and influence and what is there impact of roadside vegetation on the local air quality. Authors of the given study also are assessing the effectiveness of different green street designs in order to improve air quality. Case studies are the streets in Belgium and the Netherlands. Only a single wind direction of 90° is considered. The studies showed that roadside urban trees have a detrimental effect on the local air quality and the higher the surrounding building are, the bigger are the negative impacts of urban trees (Vos, Maiheu, Vankerkom, & Janssen, 2013).

The dissimilar idea is suggested that in some cases vegetation can be responsible for higher concentrations for traffic related pollutants, because trees obstruct the wind flow and thereby they are reducing ventilation. But the fact that roadside trees may have the negative affect on the local air quality, doesn't mean that trees in urban areas, traffic-free streets or urban parks have similar effect. The study suggests that it is better to plant roadside urban vegetation, rather than roadside tree, in order to improve the air quality. But the research was on the local scale studying the role of the urban vegetation on the roadside on the local air quality. Considering all the facts the authors suggest in a scientific way not to use urban trees on the roadside for improving air quality (Vos, Maiheu, Vankerkom, & Janssen, 2013) (Figure 24).

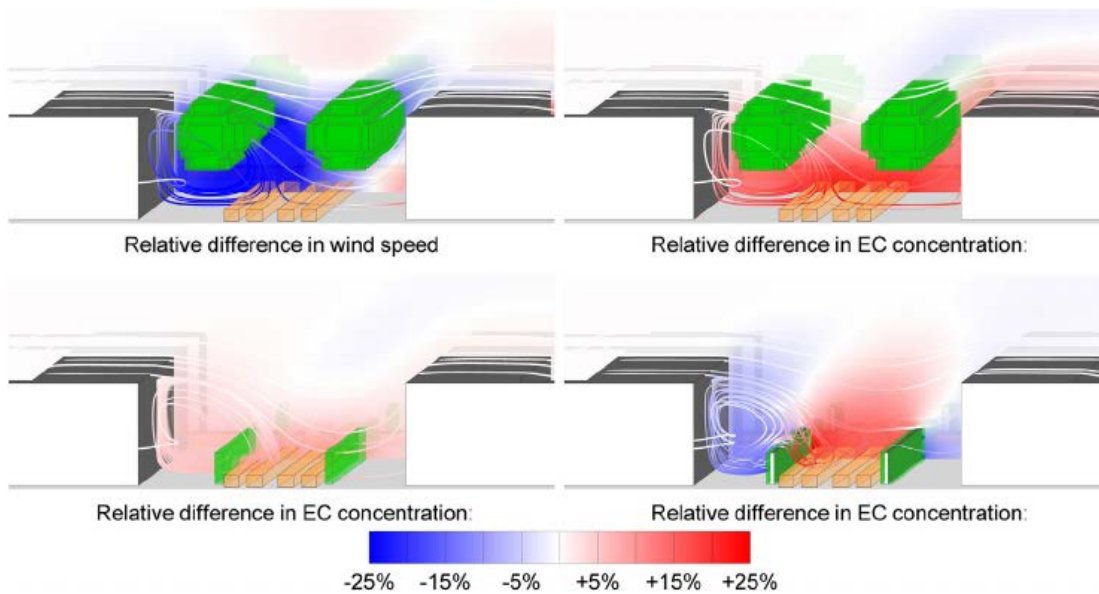


Figure 24 - Visualization of selected ENVI-met results for the street canyon geometry. The wind direction is 90 (from left to right). The ribbons correspond to streamlines and the orange bars in the centre to the location of the traffic emissions. Top left: relative difference in wind speed for the tree scenario (Vegetation scenario 2). Top right: relative difference in EC concentration for the tree scenario (Vegetation scenario 2). Bottom left: relative difference in EC concentration for the 4 m high hedge (Vegetation scenario 9). Bottom right: relative difference in EC concentration for the 4 m high green barrier (Vegetation scenario 16). All relative differences are with respect to the reference case without vegetation. (Vos, Maiheu, Vankerkom, & Janssen, 2013)

The experimental work was demonstrated with the computer model. By modelling a variety of real-life examples the authors are showing the result how the trees on the street reduce ventilation. The study can

be very useful for future urban planning in order to avoid the local air pollution and direct it in correct way (Vos, Maiheu, Vankerkom, & Janssen, 2013).

In August, 2008, in New York City, in order to promote clean air and a good health through exercise, the new campaign was initiated, which included closing Park Avenue to vehicular traffic on three Saturday mornings. Many activities were created in order to make inhabitants enjoy physical exercise without leaving the city, free bicycles were available at different stations on the Park Avenue territory, and the event was widely publicized. This provided unique opportunity to study the impact of the traffic on the near-road particulate matter in the areas of the city that are densely populated. During all these three Saturdays and also previous Fridays the PM concentrations were calculated for the analysis. The study is discussing the short-term traffic effects on the street PM level (Whitlow, Hall, Zhang, & Anguita, 2010).

In New York City in 2008, on the three Saturday mornings the Park Avenue was closed for vehicles between 7:00am and 1:00 pm for 11 km between Brooklyn Bridge and Central Park. It gave opportunity to study the PM concentration levels along the territory. The given area is high-density residential area with many commercial space. For analysis two curbside monitors were fixed in different places in the “experimental” area. In order to check the effects and the absence of the traffic, the samples were gathered during morning hours and separately in the afternoon (Whitlow, Hall, Zhang, & Anguita, 2010). (Figure 25)

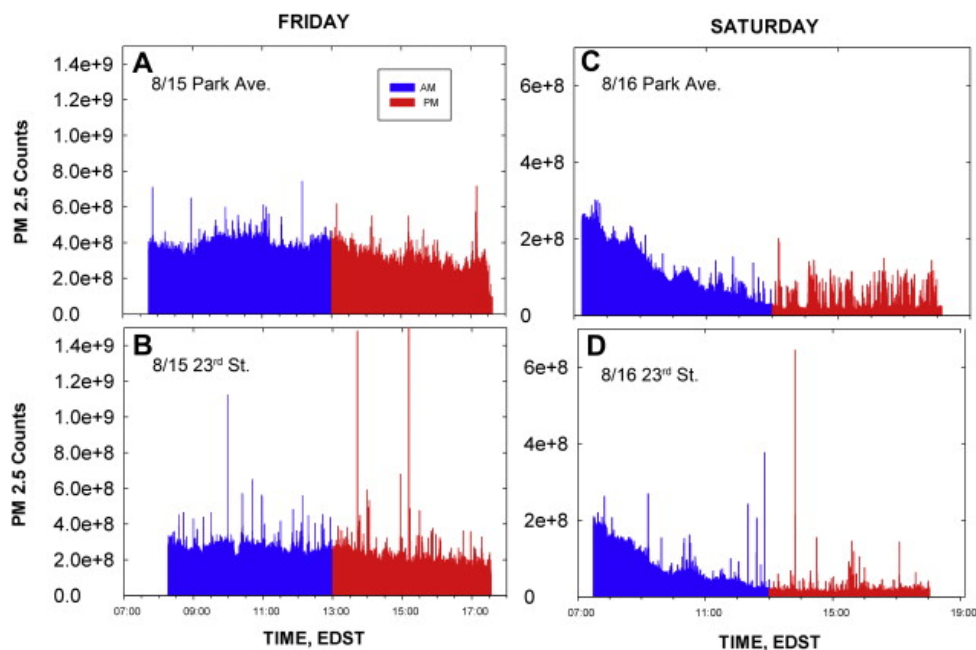


Figure 25 - describes PM<sub>2.5</sub> on the second week of experiment, on August 15-16. Three effects were observed: 1. Time by time there were stochastic concentration spikes, because of subway that is under the sidewalks, and the acceleration and deceleration of vehicle groups. It was decreased on Saturday morning when the traffic was not present. 2. Second, neighbourhood scale effects are apparent between Station 1 on Park Ave. and Station 5 on 23rd. St, Park Ave. had noticeably higher concentrations on both Friday and Saturday. 3. Authors observed the changes in the PM concentrations that were caused by the frontal air masses. They were almost double on Friday than on Saturday (Whitlow, Hall, Zhang, & Anguita, 2010).

The program “the summer street” was very successful, not only in case of checking the air quality after experiment, but also it brought the citizens outside and made their life healthy and sportier at least for

three weekends. The answer from the authors, for the question if the traffic exclusion could improve air quality, is positive. Although PM<sub>2.5</sub> responds to the change in the traffic timing, it still plays a big role for local conditions. Typically, even without free-vehicle Saturdays, the PM concentrations were higher during morning. The study suggests that closing streets more often will be needed in order to separate ground level pollution from the local traffic effects. Together the streets closures and fine-grained monitoring can be good strategy to develop rational strategies for mitigating near-road air pollution (Whitlow, Hall, Zhang, & Anguita, 2010).

Traffic emissions are related to the problems in the urban areas and their surroundings such as lung cancer risk, increasing mortality and cardiovascular diseases. Among the pollutants that are related to the traffic, black carbon (BC) is becoming the main concern in the past years. In many European cities, the main source for the black carbon is transportation sector. According to the fact that black carbon is primary and directly emitted by vehicles, it can be considered that BC is suitable proxy to quantify changes in road traffic emissions. Taking under control the emissions from black carbon can be a good way to reduce polluted air and improve quality, in order to improve the affection on public health (Titos, et al., 2015).

In this part, the effect of different transportation changes on air quality will be analyzed. Black carbon is a matter of concern among traffic-related pollutants. Diesel engines in the transportation sector are the major source of black carbon in many European urban areas. The analysis was conducted in the cities of Granada and Ljubljana. Two different models of Aethalometers were used in this study. Aethalometer measurements at different wavelengths provide insight in the chemical composition of the absorbing material. At this wavelength the absorption by organic particles and dust is very small relative to that by BC and thus the aerosol absorption can be attributed to black carbon alone (Titos, et al., 2015).

The experiment included closing the main streets for one day in Ljubljana on 22 September 2013 with length 300m, and in Granada the street on 29 June 2014. The streets were only accessible for public buses and taxis. In Ljubljana a 72% reduction of local black carbon was observed after the restriction was implemented. In Granada, after the public transportation re-organization, the significant reduction of black carbon for 37% and 33% of PM<sub>10</sub> concentrations were observed (Titos, et al., 2015). (Figure 26)

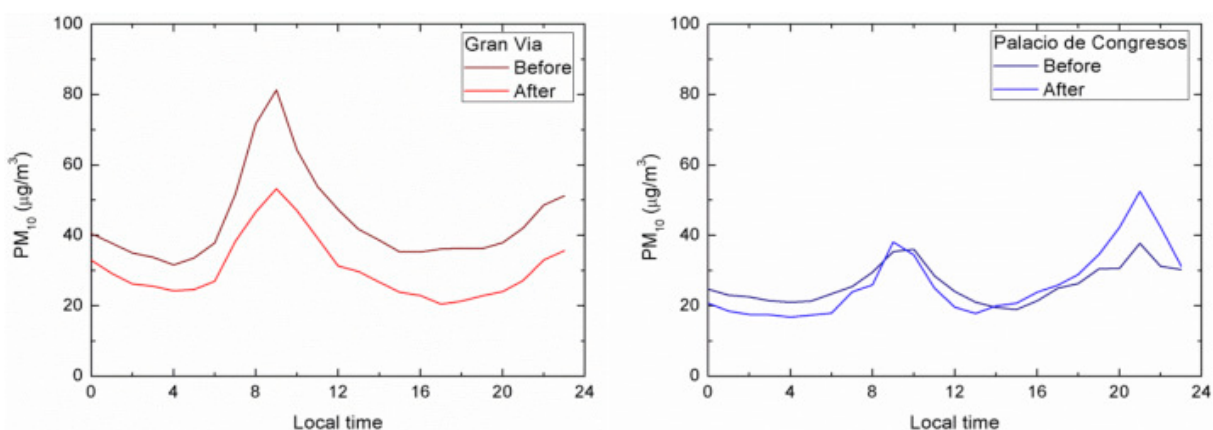


Figure 26 - Diurnal evolution of hourly PM<sub>10</sub> mass concentrations during working days before and after the LAC implementation at GV (left panel) and PC (right panel). The standard deviations have been omitted for better visualization. (Titos, et al., 2015)

According to article, closing streets to private traffic, renewal of the bus fleet and re-organization of the public transportation significantly benefit air quality. However, the improvements in air was on very local level, according to the fact that experiment was including only two main streets in the city and only for one day. Over the last decade different type of measures were implemented in different European cities, in order to improve air quality. Still their effectiveness is not so well known and most of these methods are not widespread. One of the very common measures to reduce air pollution in Europe is Low Emission Zones (LEZs). After implementation this method in Amsterdam the number of concentrations in the air reduced by 13% and 7.7%. On the other hand, showing the results for same implementations in London and Stockholm, the results are not improved for NO<sub>2</sub> concentrations, but black carbon was decreased for 47%. As a result, it can be said that using proper methods in transportation policies can be very helpful for improving the air quality in the cities (Titos, et al., 2015).

On-road traffic emissions are the largest contributor to pollutants emissions in the urban environments, and different strategies are tested in order to reduce it. These are two main ways to achieve this goal, one is to reduce number of vehicles or use alternative fuels or new technology vehicles, one of the ways to reduce traffic emissions is to change the speed circulation patterns. The speed dependency of emissions depends on the vehicle age, weight and cubic capacity of the engine. That is why there is no unique optimal speed circulation for atmospheric pollutants, but it is one of the most adopted traffic management strategies and it also benefits for reducing congestion, noise and accidents. This work analyses the changes in urban air quality and traffic conditions, in Barcelona in 2008 when the speed limit 80 km/h was introduced. Overall, the emissions after one year were reduced by 4%, the rate of mortality was reduced by 0.6%, because the implemented strategy had direct impact on welfare of 1.35 million inhabitants and it affected 3.29 million dwellers who were potentially benefited from this strategy for air quality management (Baldasanoa, Gonçalves, Soret, & Jiménez-Guerrero, 2010).

The analysis of the studied area where the measurements were implemented shows the changes of 4%-11% depends on the area. If focusing on the affected roads, the analysis shows that reductions on primary pollutants reached 5-8% on 24h average concentration and it improved the health and welfare of over 41% of the population in Metropolitan area. The best results are shown in reducing CO, NO<sub>x</sub> and PM<sub>2.5</sub> and its daily improvements in air quality reached 10-15% (Baldasanoa, Gonçalves, Soret, & Jiménez-Guerrero, 2010).

In order to reduce traffic related air pollution in the direct vicinity of a highway, the maximum speed limit was lowered from 100 to 80 km/h in Amsterdam. In the Netherlands the dispersion models suggest that in order to reduce traffic related emissions, exposure and related health effects at highways, the stricter speed limits are needed especially in the areas where people are living close to the road. The aim of this study is to see the impact on air pollution in Amsterdam after lowering the maximum speed limit from 100 to 80 km/h. After lowering the speed limit in Amsterdam in 2005 November the daily concentrations a year after were compared to daily mean concentrations in the year before, the analysis consisted from three phases (Dijkema, van der Zee, Brunekreef, & van Strien, 2008).

Using linear regression, the effect of the intervention on the roadside concentrations was studied and the same procedure was conducted to evaluate the effect on “traffic contribution”. The influence of traffic flow, traffic congestion and wind direction was taken into account. For all the components of air pollution, the linear multivariate regression analysis was performed for the “traffic contribution” concentrations (Dijkema, van der Zee, Brunekreef, & van Strien, 2008).

The results from the regression analysis of the effect after the intervention showed that concentrations of PM10 and BS decreased in the area where the method was implemented. Since the intervention PM10 concentration was decreased by 2.20 mg m<sup>-3</sup>, PM1 0.42 mg m<sup>-3</sup> and Black Smoke 3.57 mg m<sup>-3</sup>. The concentrations on the near roads where intervention was not implemented was also decreased in case of PM10 and Black Smoke. But no significant change was observed in reduction of nitrogen oxides. The reduction on the non-intervened highway section is explained by the governmental stimulation of the reduced emission vehicles. The study showed that since the speed limit was lowered it brought particulate air pollution decrease at the roadside (Dijkema, van der Zee, Brunekreef, & van Strien, 2008).

In recent years, a number of relevant measures were implemented to combine fuel and vehicle taxation in order to improve the efficiency of journeys. In Germany, since January of 2009, the motor vehicle tax, that is annual circulation tax, includes a CO<sub>2</sub> based calculation and it only refers to automobiles that were registered since that year. The goal is to implement the taxation of CO<sub>2</sub> based on motor-vehicle to lead to reduction of GHG emission. This taxation also brought other benefits, among them are generation of over 250,000 jobs, making the vehicle users to drive more efficiently and 20% of them are changing travel modes occasionally, that leads to benefits for safety, energy security and air quality (Lah, 2015).

Many cities in Europe started the implementation of the plan to ban old cars during particular hours in the city (Strohl, 2015). Until this time the cars that are produced before 1997 and motorcycles – before 2000, are forbidden to enter city centres from 8am until 8pm, but this rule will change for 2020 year and it is promised to increase hours and during all day cars that are built before 2011 will not be allowed to enter city. This plan is adopted by Parisian city council in 2015 year February.

### **3.6 REDUCING NOISE**

As said before, health effects that are connected to urban noise are of a major concern in Europe. In the cities and urban areas different environmental situation can cause unwanted noise. Mainly this noise is influenced by road traffic (Hornikx, 2016). Unpleasant noise from traffic can be controlled and directed in a way that it may disturb and harm citizens less. Urban planners and researchers are trying to find ways to direct and decrease traffic noise by studying methods that can improve quality of life of people. This actions are urgently needed also to be used for future planning processes.

Some important articles were gathered in this chapter in order to show how urban noise can be reduced. Some of the articles are showing the methods that are already implemented in different cities and the results that they showed. Other articles are experiments in build-up areas or by computational method.

The table presents the name of the authors who worked on the subject, and the dates their research was published. The aim of the table is to show shortly what kind of ways were used in order to reduce air pollution, and in some of the cases the exact results are shown (where they were given).

### **3.7 RESULTS**

In this part of the dissertation the results will be gained and discussed.

Considering all the information that was discussed in the chapter 3, the following results can be summarized:

- Congestion charges that mainly focuses on the busy roads in the cities and urban areas have a positive influence on the public transport and the environment. It helps to ease the traffic at the

busy times, and it is followed with decreasing of pollution. The immediate result of decreasing traffic was shown in Singapore after the first introduction of the changes, and it decreased traffic by 45% and road accidents- by 25%.

- Road pricing is considered to be very effective for reducing cars in the city centres, and providing healthier life for citizens by improving walking and cycling roads in order to make them more physical active.
- Closing the streets for vehicles occasionally, or in some urban areas for longer time, makes it more accessible for pedestrians, and because of less air pollution and noise, makes it more preferable to access.

For summarize implementations for air pollution reduction in general, the main methods should be outlined. Mostly they consist of creating barriers as the low boundary walls, trees, vegetation, urban green spaces and traffic regulations. Very important is to always consider the built environment and meteorological conditions where the mitigation action will be provided. The effectiveness of the barriers and other air pollution reduction methods depend on local areas.

The following results can be summarized:

- Considering the studies, it is shown that passive barriers, that are presented as the low boundary walls, trees and vegetation can help to reduce air pollution. The results from each of the barrier studies provide an evidence base that they have the potential to alter pollutant transport and dispersion patterns that their effectiveness is dependent on local geometrical and meteorological conditions.
- The existence of green areas in the city brings less affect to the health of residents and their well-being. The neighbourhood quality is increasing satisfaction due to green spaces around it. The studies show that residents with “better” accessibility to green areas show less stress-relates psychosocial symptoms, than the ones with “poorer” availability to them.
- Closing streets more often will be needed in order to separate ground level pollution from the local traffic effects. Together the streets closures and fine-grained monitoring can be good strategy to develop rational strategies for mitigating near-road air pollution.
- After the restriction was implemented to close the main streets for the private vehicle in the city surroundings, the 72% reduction of black carbon and 33% of PM<sub>10</sub> concentrations were observed. Closing streets to private traffic, renewal of the bus fleet and re-organization of the public transportation significantly benefit air quality. However, the improvements in air was on very local level.
- Creating Low Emission Zones (LEZs) in the cities show a very good effect on air pollution. The number of concentrations in the air can be reduced by 13% and 7.7% after implementation this method. On the other hand, showing the results for same implementations in other cities, the results are not improved for NO<sub>2</sub> concentrations, but black carbon was decreased for 47%.
- Reduction of traffic emissions and changing the speed circulation patterns shows the changes of 4%-11% depends on the area. If focusing on the affected roads, the analysis shows that reductions on primary pollutants reached 5-8% on 24h average concentration and it improved the health and welfare of over 41% of the population in the area. The best results are shown in reducing CO, NO<sub>x</sub> and PM<sub>2.5</sub> and its daily improvements in air quality reached 10-15% (Baldasano, Gonçalves, Soret, & Jiménez-Guerrero, 2010)
- The results from the regression analysis of the effect after the intervention of reducing speed limit from 100 to 80 km/h showed that concentrations of PM<sub>10</sub> and BS decreased in the area where the method was implemented. Since the intervention PM<sub>10</sub> concentration was decreased

by  $2.20 \text{ mg m}^{-3}$ , PM1  $0.42 \text{ mg m}^{-3}$  and Black Smoke  $3.57 \text{ mg m}^{-3}$ . The concentrations on the near roads where intervention was not implemented was also decreased in case of PM10 and Black Smoke. But no significant change was observed in reduction of nitrogen oxides. The reduction on the non-intervened highway section is explained by the governmental stimulation of the reduced emission vehicles. The study showed that since the speed limit was lowered it brought particulate air pollution decrease at the roadside.

- Vegetation can contribute sound insulation, considering the design of VGS, factors that influence their acoustic behaviour, types of plants, the thickness and composition of vegetation layer, the type of the support structure and used material. When the depth of the belt is increased, the noise is reduced. When the length of the tree belt is short, across the road, the efficiency for noise traffic shielding is decreasing. Trunk height seems to be very important detail for noise reduction. Tree belts should be positioned close to the road because the noise sources from vehicle are at low heights above the road surface. When the receiver of noise and the source are both located below the trunk, there are negative effects from this.

The distance between receiver and tree belt has very important role. The larger the distance is, the wider tree belts should be, because in case of long distance between receiver and tree belt the noise is spreading in a larger length.

- In case of macro-scale analysis, it is shown that linear and radial cities are responsible for Green Space Pattern. Under the certain traffic conditions, dispersed Green Space Pattern combined with a proper building and road attributes can be positive evidence for lower noise levels.

Radial cities can be more “quieter” than linear cities if it is compared with similar traffic and demographic conditions. The big part of radial cities follows dispersed green pattern, and it gives in most of the cases lower noise levels in the settlements.

In order to reduce traffic noise levels, it is important to consider different types of urban typology, architectural and historical background should be combined with green spaces, road and building attributes.

- The quartzite pavement generates significantly less PM<sub>10</sub> than granite pavement, the difference is almost 70%. Big difference can be seen in similar stone material pavements, but with different aggregate size. The studded tires make almost ten times higher PM<sub>10</sub> concentrations than non-studded winter tires that are less aggressive from a wear perspective. Speed has an important role, the PM<sub>10</sub> generation is highly dependent on vehicle speed. The analysis showed that maximum PM<sub>10</sub> concentrations are reached at 70 km/h. the 10 km/h increase in speed can lead to  $680 \text{ mg m}^{-3}$  increase of PM<sub>10</sub>.
- With thin pavements the noise can be reduced for 3 dB for cars and 1dB for heavy vehicle. Porous asphalt can reduce noise for 3-4 dB. Rubberized asphalt can reduce noise levels for 4 dB. Although these types of pavements can have long durability, they lose efficiency with ageing. The result showed that double layer pavement for outdoor noise reduction can reduce noise for 3.3-3.6 dB.

Mostly the solutions for reducing urban noise are found in vegetating, noise barriers and traffic policies (Table 3).

Vertical Greenery Systems (VGS) are used for urban noise reduction. In the given study two types of vegetation will be discussed and compared Green Wall and Green Façade. Green Infrastructure (GI) is a tool that provides successfully social, economic and ecological benefits for the built environment

through natural solutions. GI types are diverse and each of them are specific according to their location and place and they are very scale-dependent. If biodiversity-rich parks, gardens, green roofs and green walls, ponds, stream, woods deliver multiple ecosystem services, they can contribute to GI on the local scale, Vertical Greenery Systems (VGS) and Green Roofs for buildings can provide ecosystem services both at building and urban scale (Pérez, et al., 2016).

In case of green belts and vegetation different studies show that mostly their efficiency for sound insulation depends on different things, such as the kind of species, the green screen dimensions, it's shape as well as its location with respect to the noise source. Also plant screens thickness can be around few meters, but in case of VGS for buildings, it is difficult to have such thickness, that is why it is important to know how to use plant element for sound insulation when vegetation layers are mostly led than a meter. VGS can be classified in two general groups, Green Facades and Living Walls. These are two systems where the desired area on the building are covered by the climbing plants or hanging port shrubs by using special support structure (Pérez, et al., 2016).

Green Facades can be classified in three groups: 1. Traditional green façade-where the climbing plants are using façade material as a support. 2. Double-skin green façade-where climbing plants are supported by light structure, for creating double-skin or green curtain separated from the wall. 3. The perimeter flowerpots-where hanging shrubs are planted around the building to constitute a green curtain. Living walls are made of a panel or geotextile felts that are fixed to a vertical support or the wall structure. The given panels and geotextile felts are providing support to the vegetation (Pérez, et al., 2016).



Table 3 - Reducing noise pollution

title	author	year	context (reason for this study)	data	case study/ sample size	country	which were the problems	which were the measures implemented	efficiency/success		assessment method
									air pollution	noise	
<b>NOISE</b>											
Traffic noise reduction in Europe	L.C. den Boer, A. Schroten	ago/07	Transport noise annoys people, causes stress and illness and may sometimes even have a fatal impact. As a result, noise is very costly to society.			The Netherlands		noise emissions can be reduced at their source, through measures relating to vehicles/drivelines, tyres, road surfaces and traffic management, by reducing the exposure of people by means of anti-propagation or insulation measures			
Acoustic insulation capacity of Vertical Greenery Systems for buildings	Gabriel Pérez, Julià Coma, Camila Barreneche, Alvaro de Gracia, Miguel Urrestarazu, Silvia Burés, Luisa F. Cabeza	31/mar/16	it is important to determine whether turban Green Infrastructure through Green Roofs and VGS can provide acoustic insulation and noise control	Façades of buildings		Puigverd de Lleida, Spain		The experimental set-up; finished with a Green Wall, the other Green Façade. W data collection was repeated during two different periods.		I it can be concluded that vegetation can really contribute to the sound insulation of the building	
Guidelines for optimizing road traffic noise shielding by non-deep tree belts	Timothy Van Renterghem	12/jun/14	non-deep tree belt along a road can be an interesting solution to achieve road traffic noise reduction	streets, roadsides	street, roadside		the road traffic noise	decrease the distance between trees and increase the trunk diameter of the tree ; randomness in stem center location		the road traffic noise reduction of 8.1 dBA	non-deep tree belt along a road
Using natural means to reduce surface transport noise during propagation outdoors	Timothy Van Renterghem, Jens Forssén, Keith Attenborough, Philippe Jean, Jérôme DeFrance, Maarten Hornikx, Jian Kang	05/2015	For a sufficient improvement all tools at hand must be employed, so tackling both the source emissions as well as achieving reduction during propagation	urban environment	noise barriers, vegetation belts, ground, building envelope greening		negative impact on health and wellbeing	performing calculations for realistic road traffic configuration, including multiple lanes			
Relationship between urban green spaces and other features of urban morphology with traffic noise distribution	Efstathios Margaritis, Jian Kang	24/03/2015	over 44% of Eu population is being exposed by noise pollution limit 55dB(A)	analysis of 8 cities in UK	30km2 grid in different scales (macro, meso, micro scale)	UK	the relationship between features between urban morphology related to green spaces, roads, buildings and traffic noise distribution	Statistical analysis was used combined with GIS tool.		in order to reduce and control noise distribution in the cities the different parameters of urban morphology should be taken into consideration	GIS tool
Selection of suitable alternatives to reduce the environmental impact of road traffic noise using a fuzzy multi-criteria decision model	Alejandro Ruiz-Padillo, Diego P. Ruiz, Antonio J. Torija, Ángel Ramos-Ridao	14/03/2016	the selection of optimal technical solutions against traffic noise	the regional road network	reviewed previous publications of Andalusian Road Network	Spain	conflict with the EU's aim to encourage more sustainable modes of transport and to meet certain requirements for reducing greenhouse gases and noise emissions	different implementation were gathered in order to show the best options for different cases			

title	author	year	context (reason for this study)	data	case study/ sample size	country	which were the problems	which were the measures implemented	efficiency/success		assessment method
									air pollution	noise	
<b>NOISE</b>											
The effects of audio-visual factors on perceptions of environmental noise barrier performance	Joo Young Hong, Jin Yong Jeon	26/05/2013	both acoustic and landscape issues need to be taken into consideration to design effective noise barriers in urban environments	urban environment			the use of noise barriers considering their visual sides	5 different types of materials were chosen that are used for noise barriers		concrete barriers seem to be less annoying	audio, visual, audio-visual experiments
A soundscape approach to analyse traffic noise in the city of Taipei, Taiwan	Uou Ren Chew, Bing Sheng Wu	04/12/2015	to analyse how traffic noise affects human environment in various urban areas	city level	4 different types of land use analysed: central business district, commercial, residential, mixture of commercial and residential	Taiwan	high rate of noise	recording urban noise for future analysis		soundscape approach with potential to deal with noise in the city	
Effects of double layer porous asphalt pavement of urban streets on noise reduction	Mei Liu, Xiaoming Huang, Guoqiang Xue	06/06/2014	better asphalt pavement for keeping the traffic noise at lower level with good durability	outdoor tests						1-4 dB	



Figure 27 - Green Wall made with polyethylene modules, coconut fibre substrate and native shrubs. (Pérez, et al., 2016)

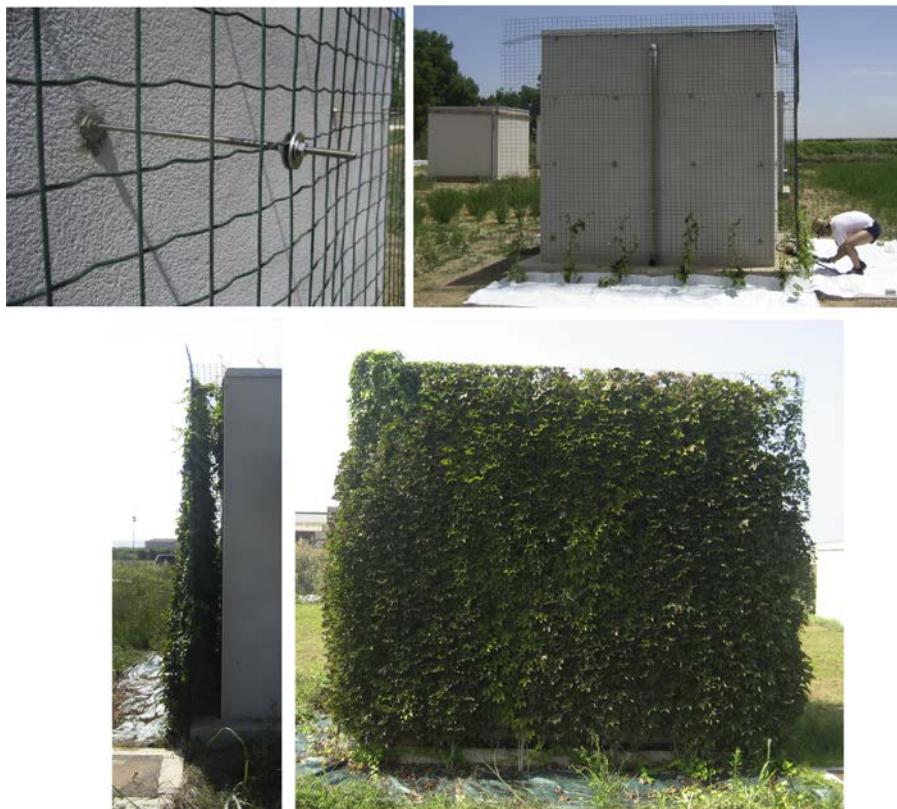


Figure 28 - Double-skin Green Façade made with wire mesh and Boston Ivy. (Pérez, et al., 2016)

The experimental set-up was located in Puigverd de Lleida, Spain. Two cubicles with the dimension of 3x3x3m were built, without any additional insulation in the walls (Figure 27, Figure 28). Both of the cubicles were identical except the difference was VGS, one of them was covered with a Green Wall and another was with a Double-skin Green Façade, to measure the sound insulation and carry out experiment, normalized pink noise was generated, emitted by twelve speakers as sound source system. The noise source was placed at the distance of 2.3m from the wall at the height of 1.2m. the wall that was measured didn't have any doors, windows or any openings, the following parameters were measured (Pérez, et al., 2016):

- -the equivalent sound pressure level outside taking measurements in various positions in front of the façade that is analysed.
- -the equivalent sound pressure level inside taking measurements in various positions inside the cubicle.
- -the level of background noise measured inside the cubicle with the source without working.
- After experimenting the two types of VGS for building these conclusions were made:
- -for traffic noise both types of thin layer vegetation 20-30cm, Green Wall and Green Façade, could provide 1 dB for sound isolation, for the pink noise Green wall could provide insulation 2 dB and Green Façade 3 dB (Pérez, et al., 2016).
- -in case of Green Wall, studies suggest in order to improve the noise insulation it is important to consider other factors, such as thickness and composition of the substrate and vegetation layers, impenetrability-sealing joints between modules and structural insulation (Pérez, et al., 2016).

The conclusion can be made that vegetation can contribute to sound insulation, considering the design of VGS, factors that influence their acoustic behaviour, types of plants, the thickness and composition of vegetation layer, the type of the support structure and used material (Pérez, et al., 2016).

During past decades there have been many studies about the noise reduction by the help of the tree belt. Different depths were considered to be helpful for this case. It was thought that the 30 meter "heavily wooded" tree belt was needed in order to reduce noise coming from the traffic (Van Renterghem, 2014).

In this paper work it is discussed how a non-deep tree belt along a road, can be a good solution in order to achieve the road traffic noise reduction. The author is studying the option that the specific choice of a planting scheme can make a tree belt along a road an efficient noise reducing measure (Van Renterghem, 2014).

The big study and interest on the leaves, show that they can have great effect for noise reduction in the streets. The foliage can interact with sound and absorb it, but it is connected with vegetation. The main goal of this work is to discover the potential for noise reduction, using tree belts. The work doesn't intend to introduce new calculation methodologies, but to show what practical measures could be when one is desiring tree belts for noise reduction along roads. The main goal of this paper is to identify the planting schemes to make improvements to reduce noise (Van Renterghem, 2014).

One way is to decrease the distance between trees and increase the trunk diameter of the tree in order to create high biomass density. In the cases when the line connection between tree belt depth and noise shielding is anticipated, if the length of the belt will be increased it will provide gathering the noise reduction at a single receiver positioned behind the belt. Randomness created by the trees which is most likely to appear by the nature is better for noise reduction (Van Renterghem, 2014). (Figure 29)

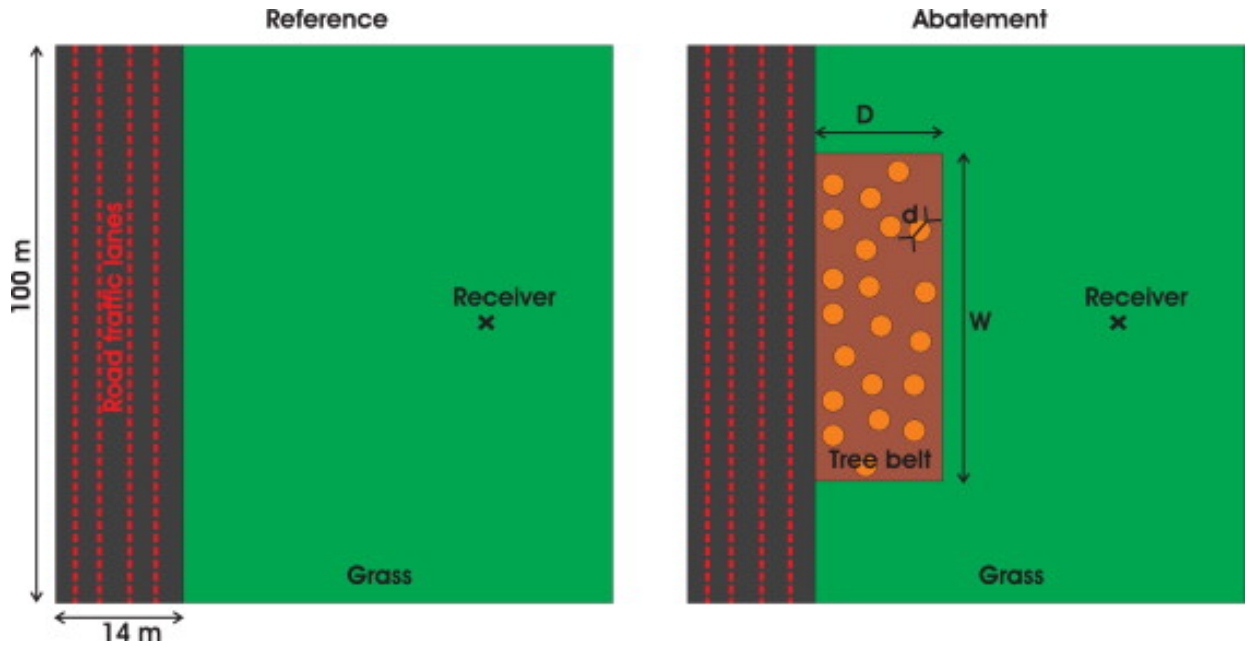


Figure 29 - Reference and abatement case considered for the numerical predictions.  $D$  indicates the depth of the tree belt (orthogonal to the road length axis),  $W$  the width (parallel to the road), and  $d$  is the diameter of the individual trees (Van Renterghem, 2014)

In case of 25% randomness in stem centre location a 15 m deep belt when trees are with diameter of 11cm trunk and are spacing the road on 1m, the road traffic noise reduction of 8.1 dB(A) is predicted. But in the same simulated situation when the trunk diameters are 22cm, the maximum achievable noise reduction is 6dBA. When the depth of the belt is increased, the noise is reduced. When the length of the tree belt is short, across the road, the efficiency for noise traffic shielding is decreasing. Trunk height seems to be very important detail for noise reduction. Tree belts should be positioned close to the road because the noise sources from vehicle are at low heights above the road surface. When the receiver of noise and the source are both located below the trunk, there are negative effects from this. The distance between receiver and tree belt has very important role. The larger the distance is, the wider tree belts should be, because in case of long distance between receiver and tree belt the noise is spreading in a larger length (Van Renterghem, 2014).

The next paper work studies the relationship between features of urban morphology related to green spaces, roads or buildings and traffic noise distribution in urban areas the analysis is in eight UK cities with different architectural and historical background, considering two different forms of settlement – linear and radial. In each city at three different levels macro-scale, meso-scale and micro-scale the 30 km<sup>2</sup> grid was defined (Margaritis & Kang, 2015).

Considering the fact that generic structure of urban morphology is a hierarchy of different characteristics at different interdependent scales involving building elements, road infrastructure and land use components, the green spaces have a direct and dynamic relation with it. It can be thought that street pattern gives specific identity to each city. For cities and towns, the “settlement form”, such as radial, linear and grid, can be used as a term to describe the network structure of district units. The interest of this article is to study the relationship between features of urban morphology and traffic noise distribution with special emphasis on urban green spaces. The analysis was studied in macro, meso and

micro-scale. In studied meso and micro-scale the main objective is to identify the effectiveness of indicators related to urban morphology in traffic noise distribution (Margaritis & Kang, 2015).

For the macro-scale three main aims are:

- The connection between traffic noise and urban morphology;
- The connection between settlement forms and green space ration, green space pattern and traffic noise;
- The effect of street typology in spreading traffic noise.

In macro and meso city scales the sample areas were taken by the grid including city centre and nearby areas., that contain a great variety of services. All the green spaces in the study were divided in two classes. One contains parks, urban forests, public squares and recreation grounds and are named “Natural Urban Green”, the second class contains the private front yards and backyards covered by grass and other small green areas that don’t belong to first category and go under the name of “Gardens”. The aim of this study was to analyse the eight cities in UK and the relationship between urban morphology in the different settlement forms and traffic noise, and how it is distributed in different areas. Using GIS and statistical analysis tool the land use parameters emphasizing on green spaces combined with buildings, roads and demographic attributes were quantified (Margaritis & Kang, 2015).

Three different city scales were measured:

- Macro-scale level: four cities with a linear form were compared to four types of radial settlement forms;
- Meso-scale level: two cities with linear and radial settlements were compared;
- Micro-scale level: analysis was focused on eight cities and their city centers.

The architectural and historical backgrounds were considered as well. From this analysis the following conclusions can be made (Margaritis & Kang, 2015): (Figure 30)

In case of macro-scale analysis, it is shown that linear and radial cities are responsible for Green Space Pattern. Under the certain traffic conditions, dispersed Green Space Pattern combined with a proper building and road attributes can be positive evidence for lower noise levels. Radial cities can be more “quieter” than linear cities if it is compared with similar traffic and demographic conditions. The big part of radial cities follows dispersed green pattern, and it gives in most of the cases lower noise levels in the settlements. The article shows that in order to reduce traffic noise levels, it is important to consider different types of urban typology, architectural and historical background should be combined with green spaces, road and building attributes (Margaritis & Kang, 2015).



Figure 30 - On the first four pictures (a,b,c,d) are shown radial formed cities. On the last four pictures (e,f,g,h) are shown linear cities. (Margaritis & Kang, 2015)

The transport noise annoys people, causes stress and illness and may sometimes even have a fatal impact. As a result, noise is very costly to society. Millions of people in Europe are affected by transport noise. Noise abatement policies will have major economic benefits. Less people will be annoyed by traffic noise and the incidence of health problems will decline. With their sleep less disturbed, people may also be more productive at work. The latter effect may be reinforced by improved cognitive performance, moreover. According to some studies the perceived benefit of noise reduction is 25 euros per household per decibel per year (den Boer & Schroten, 2007).

There are different ways to noise reduction. Firstly, noise emissions can be reduced at their source, through measures relating to vehicles/drivelines, tires, road surfaces and traffic management. Secondly, noise can be abated by reducing the exposure of people by means of anti-propagation or insulation measures. Low-noise road surfaces, such as thin-layer, double-layer, porous and poroelastic pavements, offer considerable potential to cut road noise dramatically, and are very complementary to technical measures to reduce engine, exhaust and tire noise from cars and trucks. Such surface measures have the

advantage of bringing immediate benefits, particularly for use in noise hotspots. The noise of a road can also be reduced by influencing the speed or flow of the traffic it carries. Limiting traffic speed reduces its noise, especially between 50 and 80km/h (den Boer & Schrotten, 2007).

The road traffic noise is one of the most important environmental impacts that is coming from transport systems. Different countries have their ways to deal with this problem, considering the local conditions and their knowledge, because there is no regulated process for general use. But there are methodologies that can be implemented in different conditions, and if they are used in correct way, the results can be positive against traffic noise (Ruiz-Padillo, P. Ruiz, J. Torija, & Ramos-Ridao, 2016).

In order to ensure the safety of human health, it is important to create technical solutions, gathering all the implemented ways that guarantee to be able to deal with traffic noise. It is important to generate strategic noise mapping and noise action plans to deal with the problem efficiently. Reduction of traffic noise can be divided in three alternatives (Ruiz-Padillo, P. Ruiz, J. Torija, & Ramos-Ridao, 2016): (Figure 31)

- First is to reduce the emission of the noise source;
- Second is to modify obstacles between the source and receiver (with barriers);
- Third is to reduce noise directly on the receiver, by making insulations on facades and windows.

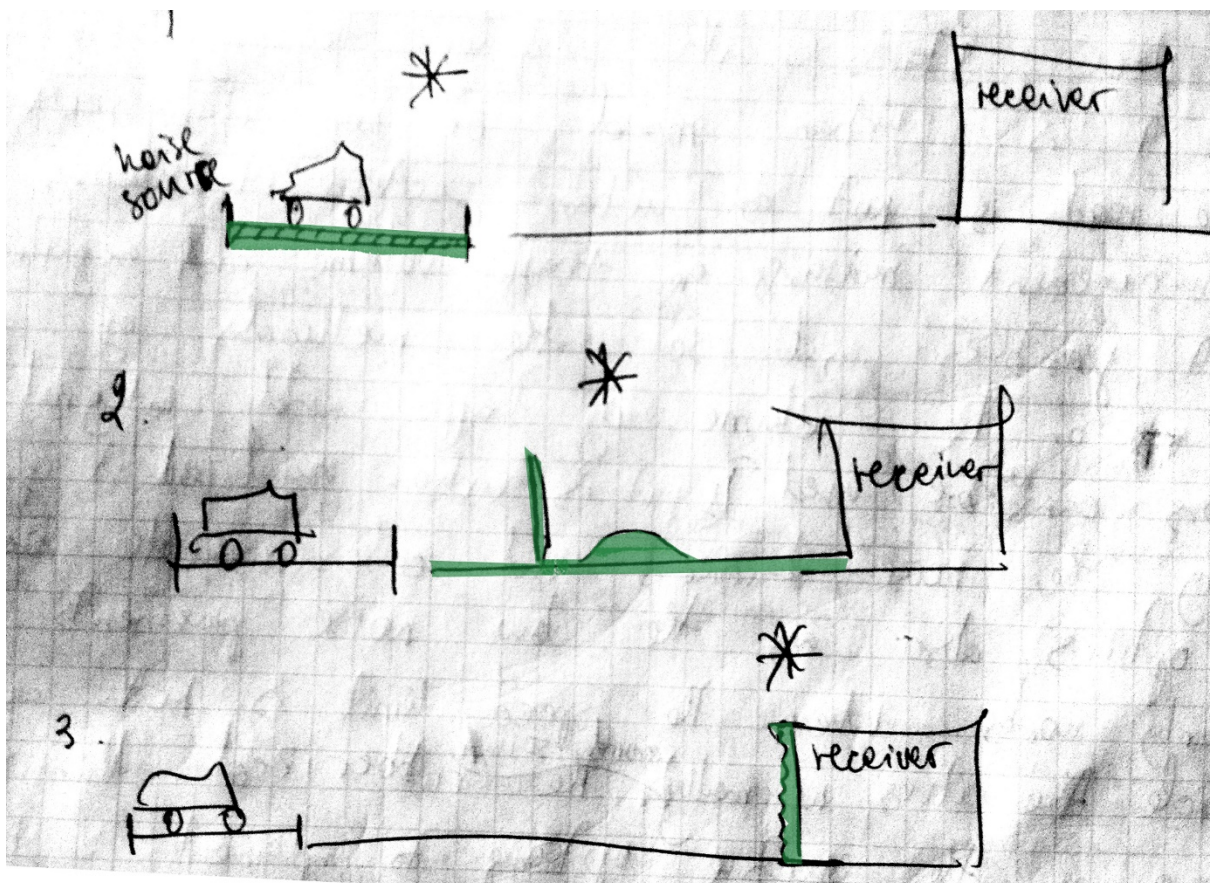


Figure 31 - Three alternatives how traffic noise can be reduced

The ways of traffic noise reduction can be chosen differently, they can be divided in five categories (Ruiz-Padillo, P. Ruiz, J. Torija, & Ramos-Ridao, 2016):

1. Noise barriers. It is one of the most representative types of these barriers and they can be of two types: earth berms and noise barrier walls/acoustic screens.
2. Low noise pavements. It has very common use in Europe and it can be three different types: porous asphalt, rubberized mixture and porous concrete.
3. Traffic management measures. There are three types of it: action on the volume of traffic, action on the vehicle speed and integral traffic regulation plan and policies for promoting urban public transport.
4. Building insulation. Actions on the facades and windows.
5. Undergrounding or covering the road with the design of a false tunnel.

The process to select the most useful/correct tool for the given place, starts with defining the type of road, whether it is urban road or non-urban section. If the road is not an urban section, it means that traffic management measures on traffic volume and regulations are not feasible and so the methods of action on the volume of traffic and integral traffic regulations cannot be used. If it is urban road and it is inside the city, the noise barriers and covering the roads is not the good option, as well as the low noise pavements, because these methods mainly work where the speed limit is not as low as inside the cities (normally around 50 km/h). the rubberized thin layers are one of the effective options to implement in the city roads (Ruiz-Padillo, P. Ruiz, J. Torija, & Ramos-Ridao, 2016).

This methodology should be used after noise maps are done and general characterization of the road is made. The methods that are provided are reasonable and appropriate. There is not right solution suggested in this paper work, but some proposals and alternatives for mitigation, in future these methods can be used while creating new roads or while improving and restructuring existing one (Ruiz-Padillo, P. Ruiz, J. Torija, & Ramos-Ridao, 2016).

In the last years different studies show that outdoor air pollution is strongly contributed from road pavements and tires. Mostly these events occur during winter and spring in dry periods. The episodes mostly happen due to the use of studded tires and winter gritting, and this problem is widely spread in northern countries, such as Norway, Finland and Sweden. In many cities of Norway, they already introduced fees for drivers with studded tires. Although the more strength pavements are introduced for many years, still every year 100000 tons of pavement is used in winter in Sweden. This study will investigate type of tires, pavements and speed limits in the environment (Gustafsson, et al., 2008).

The circular road simulation was made by the Swedish National Road and Transport Research Institute in order to generate wear particles. The road simulator has ability to run four wheel around the track, with chosen speed that varies from 0 to 70 km/h. Three different sets were made for checking the effect of pavement wear and how it generates PM<sub>10</sub> (Gustafsson, et al., 2008):

1. Type of pavement;
2. Type of tires;
3. Speed.

Three different type of pavements were used (Gustafsson, et al., 2008):

1. Asphalt concrete consisting of granite stone material with 16 mm maximum aggregate size;
2. A stone mastic asphalt of quartzite stone material with 16mm maximum aggregate size;
3. And another stone mastic asphalt of another quartzite stone material with 11mm maximum aggregate size.

Three different types of tires were studied, all from the same manufacturer (Gustafsson, et al., 2008):

1. Studded winter tires;
2. Friction tires (non-studded winter);
3. Summer tires.

Speed can be changing from 0 to 70 km/h in this experiment. While studying pavements and tires, the speed was increasing from 30 to 50 km/h and eventually 70 km/h, during or less than in 2 min. The conclusion from results are the following (Gustafsson, et al., 2008):

- The quartzite pavement generates significantly less PM<sub>10</sub> than granite pavement, the difference is almost 70%.
- Big difference can be seen in similar stone material pavements, but with different aggregate size.
- The studded tires make almost tend of times higher PM<sub>10</sub> concentrations than non-studded winter tires, that are less aggressive from a wear perspective.
- Speed has an important role, the PM<sub>10</sub> generation is highly dependent on vehicle speed. The analysis showed that maximum PM<sub>10</sub> concentrations are reached at 70 km/h. the 10 km/h increase in speed can lead to 680mg m<sup>-3</sup> increase of PM<sub>10</sub>.

The control of the urban noise from its' source normally involves providing of low noise pavements and regular maintenance. The efficiency of double-layer porous asphalt was studied. The traffic noise is increased with urbanization and city population growth and is often recognized as 'unwanted sound' (Liu, Huang, & Xue, 2016).

When noise is being controlled at the source, the methods mainly includes providing low noise pavements and/or vehicle tires for making less noise. If the noise is not controlled from the source, then noise barriers, vegetation and other methods are needed in order to prevent the receiver from harmful noise. As the effective way to control noise coming from the source, low noise pavements are being a subject that many researchers study and try to improve. From the beginning the porous asphalt was used for as the drainage in order to be useful while heavy rainfall and to reduce the water from the surface. Porous asphalt was developed in USA and is being used largely in Europe. It is mixture of small amount of aggregates entailing pavements with relatively large air voids. While there is interaction between tires and pavement, air voids absorb a large amount of noise. Another type of pavement is thin small aggregates asphalt pavement. These type of pavements are normally produced by hot mix materials, which are being laid to a thickness of between 20 and 40mm. the surface of this pavement reflects the noise and also absorbs the vibration energy owing to aggregates and deep texture depth. Third type of pavement is rubberized asphalt pavement that is a mixture with reclaim crumb rubber (10-20%). This rubber adds elasticity to the asphalt mastic. The complex deformation of pavements under the wheels creates absorption of the noise. This type of pavement helps to reduce traffic noise significantly (Liu, Huang, & Xue, 2016).

Studies show that with thin pavements the noise can be reduced for 3 dB for cars and 1dB for heavy vehicle. Porous asphalt can reduce noise for 3-4 dB. Rubberized asphalt can reduce noise levels for 4 dB. Although these types of pavements can have long durability, they lose efficiency with ageing. The authors of this study suggest a double layer porous asphalt pavement for sustainable noise reduction, which can also provide long lasting use. The proposed pavement contains two layers. The top layer has fine aggregates and is designed to avoid blocking and easy loss of material. The layer below contains large air void ratios that also work as the mitigation tubes for air flow that is created by rolling tires. The two layers are connector in a way that the drainage of rain water is avoiding splash and spray. The high air void ratios are the reason for this type of pavement to be efficient. The thickness of the top layer is

2cm, and for the layer below is 4cm. The result showed that double layer pavement for outdoor noise reduction can reduce noise for 3.3-3.6 dB (Liu, Huang, & Xue, 2016).

As the result of environmental growth, the need of the noise barriers has increased. For the most efficient isolation both acoustic and landscape issues should be analysed and taken into consideration. In this study the performance of noise barriers will be introduced combined with visual sides. Five different barrier types will be discussed (Young Hong & Yong Jeon, 2014):

1. Aluminium;
2. Timber;
3. Translucent acrylic;
4. Concrete;
5. Vegetated.

As said before, three main parts should be considered in the environmental noise source: the noise source by itself, the path between source and the receiver and the receiver. From the beginning the noise barriers were made to protect receiver from the noise in the environment. However, the visual side of the noise barriers also should be taken into consideration. Authors in this study think, that noise barriers also need to have visually good design and to respond appropriately to the landscape and environment. Chosen five materials (aluminum, timber, translucent acrylic, concrete and vegetation) are often used in the urban spaces. For the measurements ten environmental barriers were designed for the experiment and installed in the urban areas between residential areas and roads. The average height of the barriers was 4.8m, the deviation was 1.1m, all of them were standing 2m away from the road (Young Hong & Yong Jeon, 2014) (see Figure 32).

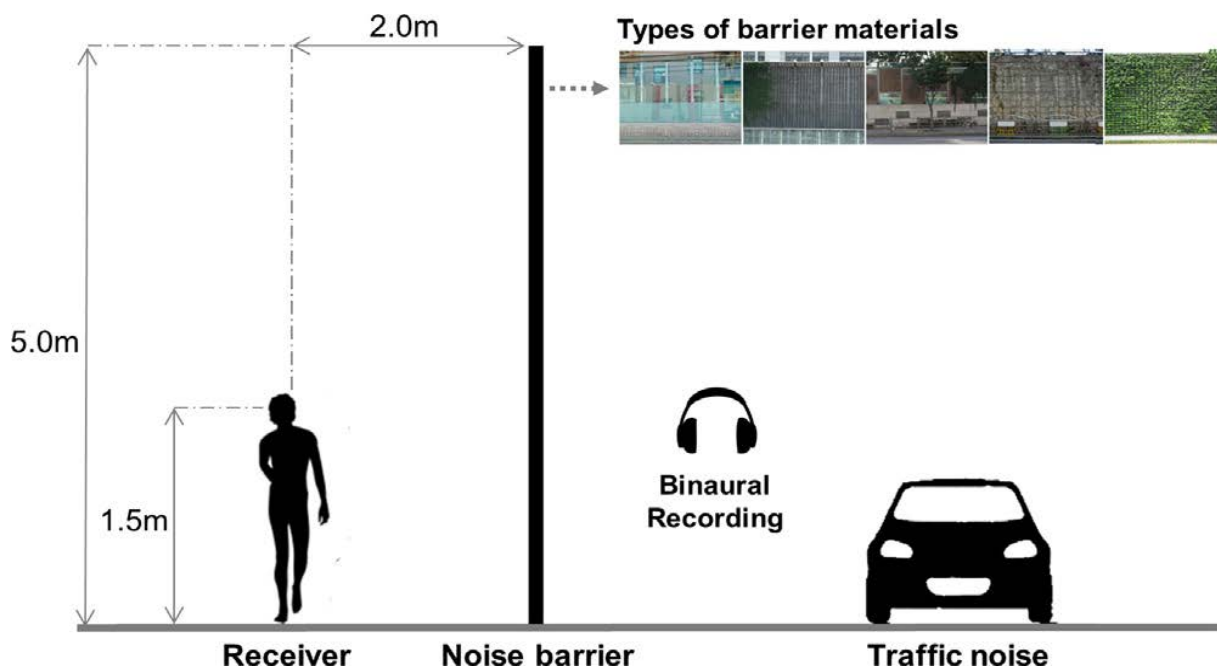


Figure 32 - Scheme of the simulated conditions of the laboratory experiments (Young Hong & Yong Jeon, 2014)

The result showed that the timber and aluminium barriers worked as more annoying than the others. Among these five materials, concrete showed the lowest annoyance on the scale. Regardless the visual annoyance, timber and aluminium barriers had the least frequencies, that were below 250 Hz (Young Hong & Yong Jeon, 2014).

As said before, traffic noise is proven to be serious issue in urbanized areas and it brings annoyance and health problems. Normally, traditional approaches are focused to measure the amplitude and frequency of noise, but the measurements not always help the researchers to distinguish the main features of noise on different types of land use (Chew & Wu, 2016). Three main parameters are distinguished for the analysis of sound scape:

- Amplitude
- Frequency
- Time

These three components are often selected to measure noise in urban environments. As the study area, with high rate of noise by rapid urbanization, was chosen the city of Taipei. In order to analyze the relation between main types of urban shapes and traffic noise, four different type of land use were selected (Chew & Wu, 2016):

- Central business district;
- Commercial;
- Residential;
- Mixture of commercial and residential sites.

During weekdays these four different type of lands were examined with sound recording. For the procedure of sound recording pair of identical sound level meters were used to record urban noise in the given four areas. the pairs of sound recordings were positioned on the different sides of the streets. The sound was recorded in the streets for 15 minutes during three time periods (Chew & Wu, 2016):

- Morning-8:00-8:30
- Afternoon – 15:00-15:30
- Evening – 20:30-21:00

This actions were done from 3 of December until the 7 of December in 2012. It is very important to understand the relation between sounds and types of land use. After the recordings were done, all of them were listened and analyzed. Among sounds were the sounds of traffic, birds, people and construction work. All the recordings show that the main part from sounds is coming from traffic noise (Chew & Wu, 2016).

The study doesn't discuss the typical methods for reducing the noise, such as noise barriers, water features. The study suggests the method that was used in berlin, that provides installed speakers in the urban area in order to mask the traffic noise, and that imitates the sound of the ocean or birdsong from the crossroad. The purpose of this is to create pleasant noise for people on the playground. The unwanted noise that is coming from traffic can be measured and analysed by computer, and for further action, the process can be applied in order to change the soundscape of the traffic noise (Chew & Wu, 2016) (see Figure 33).

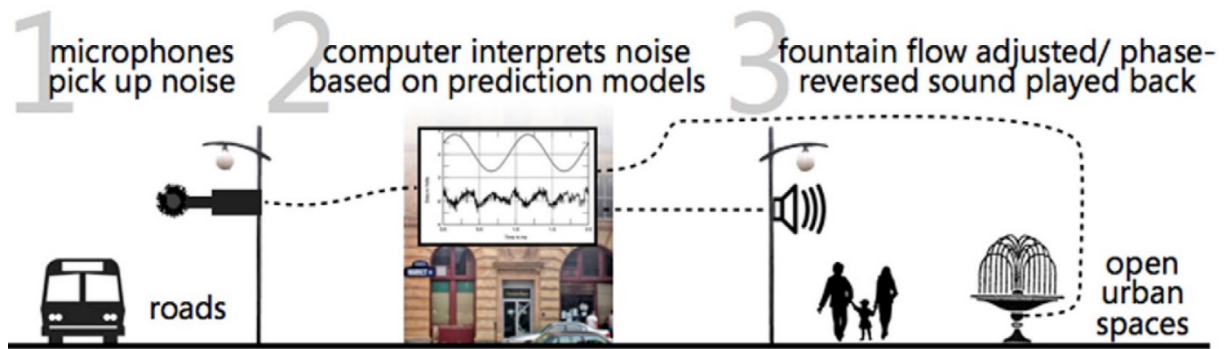


Figure 33 - A suggestion for a more active noise mitigation plan. (Chew & Wu, 2016)

As a result, after the analysis was made, the study conducts spatial-temporal analysis by the combination of the three parameters that shows the concept of how different type of traffic noise in urban landscape dominate during periods of day. As the analysis is made, the study concludes that the soundscape approach has potential to handle with the noise problems in the cities. The soundscape approach can help future planners to reduce noise levels in the city, and also to consider the right measures (Chew & Wu, 2016).



# 4 IMPLEMENTATION

## 4.1 INTRODUCTION

This chapter discusses the implementation of the methodology that was given in this work, with the purpose to decrease traffic and pollution in the cities. In order to use the gathered methods, the capital of Georgia will be taken as an example, the city called Tbilisi.

The first part of the given chapter will describe the city, with its main roads and the problematic areas where the traffic is mostly common.

The second section of this chapter, will describe the methodology for the policy makers, on how to use the given work for improving the quality of life, and which are the best ways that are providing good solutions for the cities.

The next section will be implementation of some of the methods that were given in this work before for the city of Tbilisi. The most applicable practices will be chosen.

## 4.2 THE DESCRIPTION OF TBILISI

Tbilisi is the capital of Georgia and it is the largest city inside the country. The population roughly equals to 1.1 million inhabitants, that is almost the one fourth of the population of Georgia (Figure 34) (World Population Prospects , 2016). During the last years the number of inhabitants in the city is growing, due to the fact that the capital is becoming active in case of business and industry (Brinkhoff, 2016).

	Name	Adm.	Population Census (C) 2014-11-05
1	Tbilisi	TB	1,062,282
2	Batumi	AJ	152,839
3	Kutaisi	IM	147,635
4	Rustavi	KK	125,103
5	Sukhumi	AB	62,914
6	Gori	SK	48,143
7	Zugdidi	SZ	42,998
8	Poti	SZ	41,465
9	Tskhinvali	JO	30,456

Figure 34 - Major Cities in Georgia (Brinkhoff, 2016)

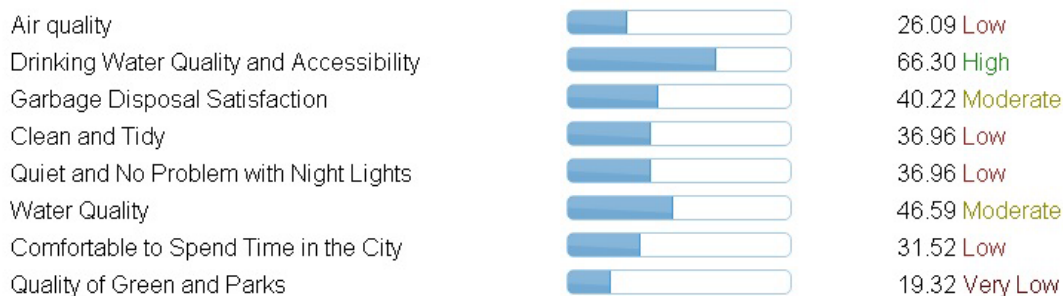
The city is not ready for the growth and such number of the inhabitants, as it is very old city, with the historical city centre, that includes in itself small streets. The structure of the city by itself doesn't give a chance to the new industrialisation to develop. According to the latest data from the city hall, there were around 400000 private cars in Tbilisi by the year of 2016 (Agenda.ge , 2016). The number of vehicles seems to be increasing and this is thought to be the reason for the increased traffic that is followed by the air pollution and noise.

Unfortunately, there is no data available for the level of the polluted air or the noise that exists in the city for the moment. But there is the website available, where people (both-inhabitants and tourists) are free to fill in the questionnaire about the quality of life in Tbilisi, text includes the questions such as the air pollution in the city and noise and light pollution. According to the given statistics, the purity and cleanliness is not on the high level in the capital, as it is desired to be (Figure 35) (www.numbeo.com, 2016).

### Pollution in Tbilisi, Georgia



### Purity and Cleanliness in Tbilisi, Georgia



Contributors: 23

Figure 35 - Pollution in Tbilisi (www.numbeo.com, 2016)

## 4.3 STRATEGY FOR IMPLEMENTATION

The methods in order to decrease air pollution and noise in the cities are various as one could see on chapter 3. In this part of the dissertation the city of Tbilisi was chosen to illustrate the use of the methodology suggested in this work.

*Firstly*, is important to know the scale of the city, that is to say, the size of the city, in terms of area and population.

- Some of the measures to implement are effective in the bigger scale, others are preferred in punctual situations, for instance, by being implemented on façades of the houses.

- Another point that should be stressed is associated with the implementation point of view. Some of the measures have to be implemented by the initiative of municipal authorities while another will depend on the option of the property owner. For this reason, two groups were considered in this work:

The **first group** (global/general) include measures whose implementation concerns urban planning and a deeper involvement of the public under a framework defined by municipal authorities, namely:

- changes in transportation policies (better public transport (including BRT), implementation of congestion charging system or road pricing; ban old cars; improve the incentives to acquire electric vehicles, etc.)
- Traffic management measures, like speed limitation; diverse parking space pricing, park&ride systems, parking areas connected with public transportation, etc.).
- Implementation of mitigation measures like green belts or noise barriers;

The **second group** (local/specific) is for the methods that can be used for more local scale, at the street level or in specific areas inside the city, such as:

- Implementation of low noise pavements;
- Closing streets for vehicles, some days of the years or just for good and transform that street into a pedestrian one;
- Creating new tunnels in the city that will also provide new public areas for the city, in which the vegetation can improve air quality and bring new forms of quality of life for urban citizens
- Creating new VGS (Vegetation Greenery System) in the city with new parks and gardens

This primary division of solutions may be useful, essentially for policy makers and also for designers to choose the mitigation measures that are the most suitable for their situation and their city.

#### 4.4 APPLICATION OF THE METHODOLOGY TO TBILISI

The gathered methods were analysed, and the listed implementation will be adjusted to the city of Tbilisi. The lack of the information about the air pollution and noise levels in the capital of Georgia, at one point makes it harder to choose the most correct approaches, but at the same time it gives the opportunity to use the methods in the way that seems more correct and in this case there are no restriction forbidding any of the implementations.

In order to decrease the number of private vehicles in the city, firstly it will be needed to improve the quality and effectiveness of the public transport in the city. When the city is providing the public transport with the high quality, it gives the citizens the choice that they can make between using the transport during the day. As for Tbilisi, as it was very common in past century, I would suggest to bring back the tradition for using tram in the city, it would act as the traditional public transport for the city and this would decrease the number of private car users in the city.

To reduce number of private cars in the city is also possible by introducing congestion charging system to the city. Pricing the roads in the city centre, or main streets is a good way to stop private car users to drive through the city. But in order to accomplish this method in Tbilisi, I would also suggest to provide the vertical parking lots nearby the central streets, in order to make this system easier for inhabitants. They could leave their cars in the entrance of the city centres and use public transport instead of their own. This method may also be implemented in the larger scale, such as in the entrances of the city parishes. The price may be the same or it may be increasing close to the city centre. The major concern in this situation is to have a high quality of public transport that provides good connectivity in the different parts of the city.

Continuing the pricing system, in order to decrease number of cars in the city I would suggest to forbid the free parking lots in the city, especially the major streets in the center. Creating the new vertical parking lots will also help to evaluate this method.

Mostly the methods listed above are connected to each other as a chain, so starting the implementation of each of them may help to accelerate to develop the processes.

Except the changes that are possible to make in the traffic system, there is the list of the implementations for reducing air pollution and noise. For the beginning, multiplication of the greenery in the city will be the best solution, for reducing both, air pollution and noise. There are different ways to use greenery systems.

The green belts can be planted in the suburban areas, where the settlements are less. The most effective ones are with the deep of 15 meters, so they can be planted in the entrances of the city, along the roadside. Considering the big spots for the greenery system inside the city, the number of different sized city parks can be added, to function as the 'lungs' of the city. In order to have the green structure of the city as the one whole system, I would suggest for the greenery in the city to be connected with the green elements, such as VGS and the greenery along the roadside.

In case of VGS (vertical greenery system) can have positive effect on Tbilisi. Firstly, the method will improve the air quality, and secondly, it will serve as the sound isolation for inhabitants.

For more detailed plan to decrease pollution in the city, the map of Tbilisi was taken to choose the implementations for particular area. The given map below (Figure 36) shows the roads of the city Tbilisi. (Maphill, 2015)

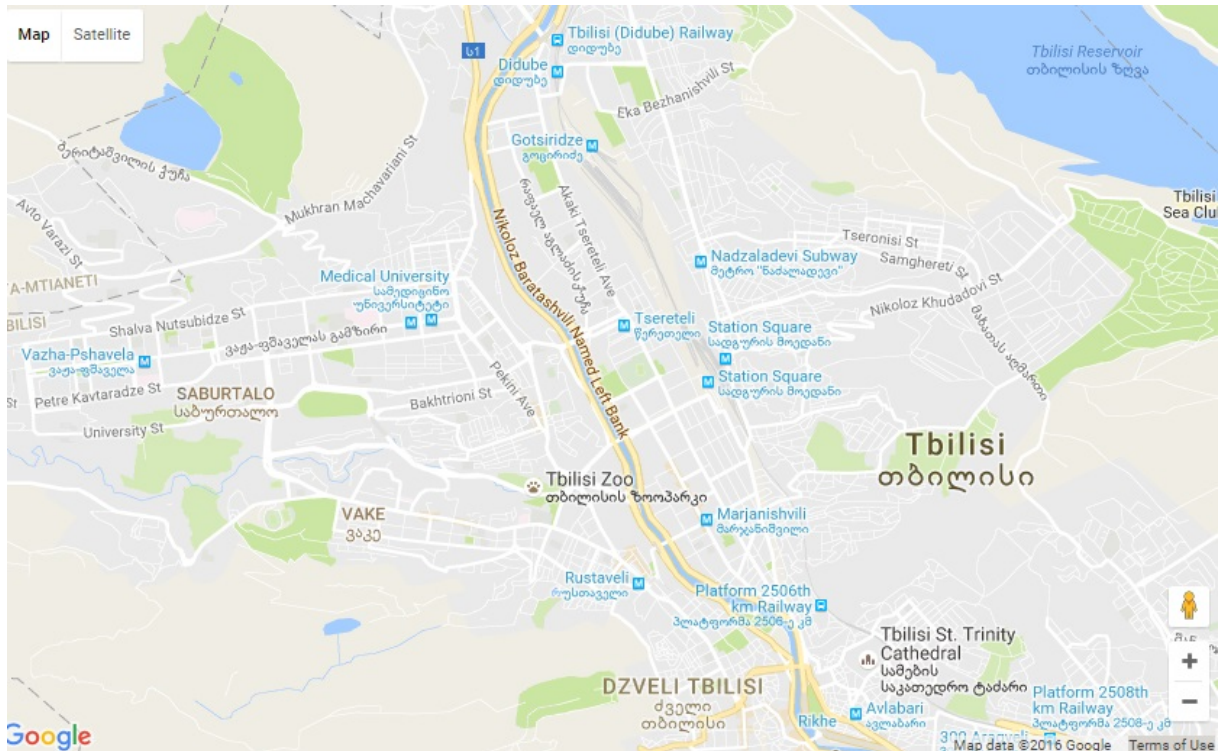


Figure 36 - Detailed Road Map of Tbilisi (Maphill, 2015)

In order to choose the places that need implementations in the city the most, the time of the rush hour was chosen, because it will be easier to see where the problem is. The given map below, shows the roads of the city Tbilisi. The colors of the road describe 4 different conditions (Figure 37):

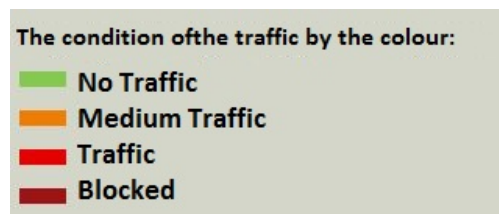


Figure 37 - The condition of the traffic by the color (MyMap, 2016)

The map was taken from the website that shows in the different part of the day where the traffic is. Such map was used on purpose in order to choose the problematic areas in the city. The map was recorded on the rush hour, at 18:45 (it is the time when most of the inhabitants are leaving work).

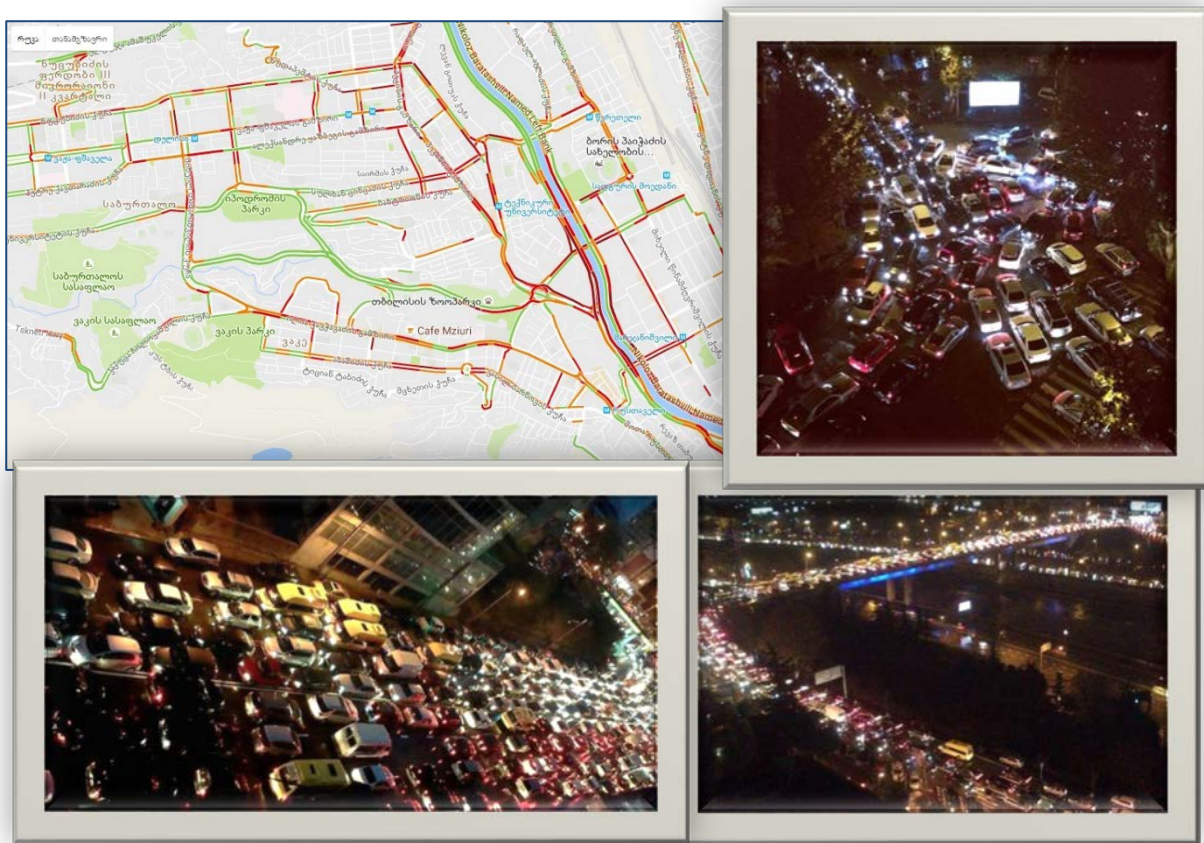


Figure 38 - The map of traffic in Tbilisi (MyMap, 2016)

As it is shown on the map (Figure 38), the most problematic areas in the city during rush hour are on the riverside and the roundabout next to it. These two places are the areas that are mostly crowded by the traffic. So it will be correct to start implementation from this spots.

Firstly, in order to decrease noise, it will be correct to use the low noise pavements, especially in the area where is the roundabout, because this part is surrounded with the houses with the high density. During the traffic when the cars are stuck, the noise is creating disturbing sound that are bringing harm to human health. So to make the level of the noise less it will be good solution to change the existing pavements with low noise.

Another good solution for noise mitigation will be to create new tunnels along the street. This may reduce noise and as well air pollution that occurs on the streets while traffic. But here the accuracy is needed, because, when it is tunnel, all the polluted air that is inside, comes out from the tunnel entrances, and in this case, the entrances should be covered in greenery, in order to deal with polluted air.

Considering the air pollution, the doubling of the existing greenery is needed, both on the riverside and the area around the roundabout. Completing the greenery on the both dies of the street, will help to reduce noise and air pollution. Also starting the implementations for the VGS is of a major importance.

And for the finalization the implementation of the possible primary implementations, introducing the city to the car free days, will be very useful, as for the city, also for the country and the region as well.

#### 4.5 RESULTS

The provided proposal, aims to decrease air pollution, noise and traffic in the capital of Georgia, Tbilisi. The main reason for implementation is to improve the quality of life of the inhabitants and the environment in the city, by decreasing the air pollution and noise.

In Figure 40 are given the main gathered changes that can be made in the city:

Firstly in order to reduce traffic in the city the proposal is to bring back the tram, which will act as the part of the renewed public transport. Except the changed in transport system, for unloading the traffic in the city, creating more spaces in the city to work as the parking lots will be very useful, because it will give the chance to the drivers of private vehicles, to reach to the point near the parking lot, and after leaving the car change it and use public transport.

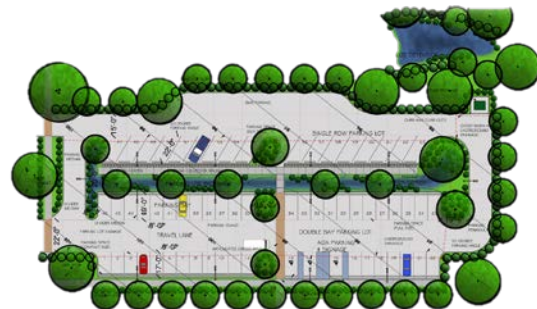


Figure 39 - Reducing traffic

In order to reduce air pollution, different implementations are suggested as well, in the given situation the following methods are chosen:

- Using greenery system;
- Implement speed limitation;
- Banning old cars.

In Figure 41, the map is given, where the restrictions with speed limitations are suggested, such as reducing speed on the river side and the city center. The method will help to reduce traffic and it is helpful for air pollution and noise reduction. The proposal is to decrease the speed on the riverside from 70 km/h to 50 km/h, and in the central area from 60 km/h to 40 km/h.

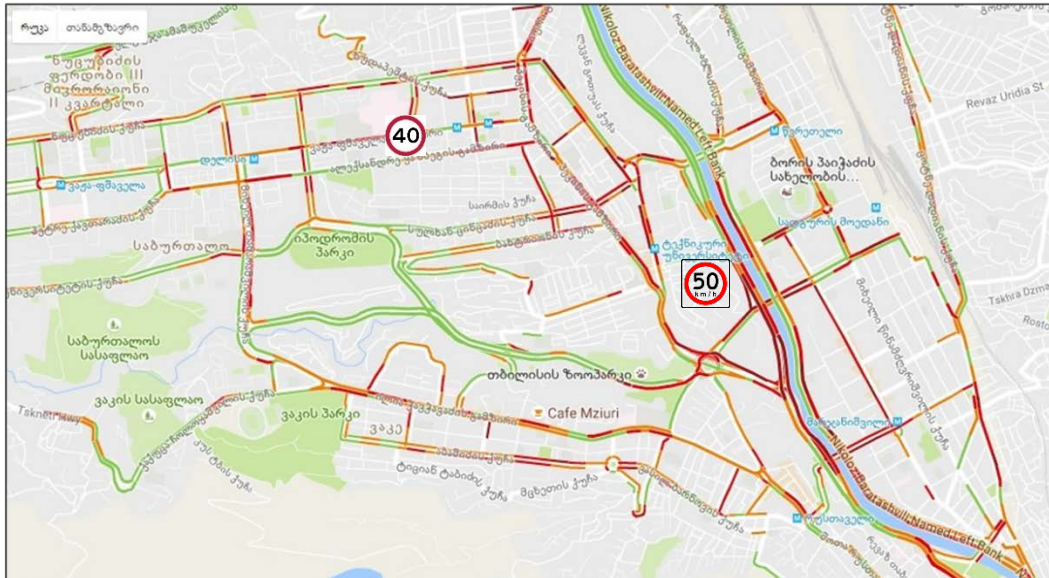


Figure 40 - Reducing air pollution

In order to reduce noise, as indicated in Figure 42, the following methods are discussed for case study of the city Tbilisi:

- Starting using low noise pavements;
- Creating new tunnels;
- Using VGS.

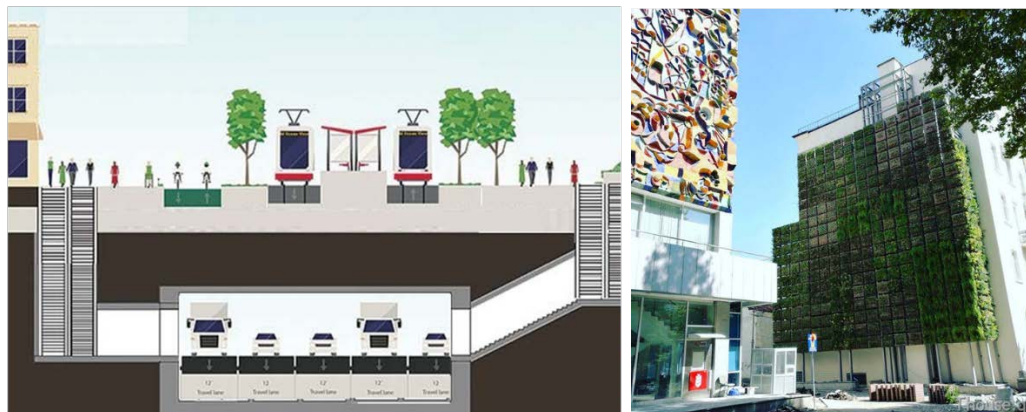
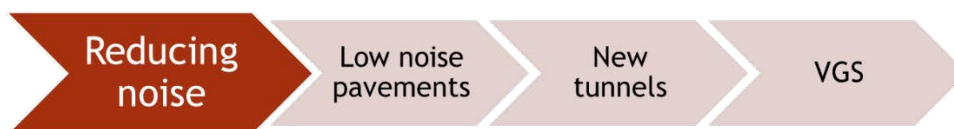


Figure 41 - Reducing noise

If the city landscape is giving the opportunity to create underground tunnels, there is a possibility to bring all the transport types underground and leave on the street level the public transport such as tram, and leave the roads for cycling and pedestrians, this will decrease the noise levels in the city and will make it more liveable and attractive. The second suggested method is to start using VGS systems, that are already starting to be used in Tbilisi and the results should be positive, that will be reduction of the noise for the citizens while they are indoors.

Unfortunately, no existence of data or information about the pollution levels in the city, makes it harder to choose the best practices that could improve the quality of the environment in the city. But already the proven methods were chosen and suggested in a way to decrease the pollution.

The main aim of this chapter was to mention, that the possible changes can be done in the cities like Tbilisi, where the policy makers haven't started the implementation of methods yet, in order to improve quality of life. There are various number of solutions. Most of them can work as the chain that will bring advantages to the cities and improve the quality of environment. For the future work, it is desirable to have the data about the particular city, in order to make more detailed working plan, with the best suitable methods that will work for improving the life of the inhabitants.



# 5 CONCLUSIONS

## 5.1 MAIN CONCLUSIONS

The presented dissertation investigates different methods to improve quality of life by reducing air pollution and noise. The two pollutants mentioned before are presented as the major problem concerning health effects.

The study has shown that there are several methods how to deal with air pollution and noise. Almost all of them require observation for the specific areas, where the methods will be implemented, because the success of the mitigation action is not only depended on the method, but also on the local weather conditions, environment, etc.

This dissertation work gathers the methods that were already implemented in the cities and urban areas, some methods are the results from the experiments with build-up areas or computer programs.

Although the study was mainly pointing out air pollution and noise, it will be beneficial for other problems, such as climate change.

Future study of this subject will be a big subject of interest, in order to go deeper with the subject and implement gained methods to the particular city or the area. Because of the relevance of the subject, many authors and researchers are working on it. So in future more interesting findings can be discovered.

Provided study was conducted on finding and analysing the strategies for mitigation action for air pollution and noise, in order to improve quality of life in the cities and urban areas. Citizens are suffering from polluted areas that is led by urbanization and industrialization. Every person has the right to live in the good environment equally.

Quality of life is essential for human well-being. For people it simply means living in the green environment, having calm streets, breathing fresh air and listening to the sound of the birds. Nowadays the main goal of urban planners is to create the atmosphere where citizens will feel comfortable and harmless.

Sustainable urban planning plays big role in nowadays. It is able to create the guaranteed environment for the future generations where it will be possible to survive and have good quality of life. The ways to decrease pollution is one of the major concerns of urban planners. Air pollution and noise are by itself the part of the reason for climate change. With the problem all planet is having the trouble. For creating better living spaces and future well-being, starting mitigation action plans are needed today.

Quality of life is the result of the way cities can function today. Economic, social and environmental factors are directly connected to quality of life. When city is growing, it gets always harder to control number of private vehicles in the city, always provide good public transport with the amount of what is needed, controlling air pollution and noise, etc.

Industrialization brought huge changes in the cities, the number of inhabitants are growing and respectively the number of private vehicles as well. There are, especially in Europe, old historical cities that cannot handle modern traffic. Even the bigger cities and urban areas are not usually prepared for such amount of polluted air and noise. Deforestation, willingness to live in the city, having the private vehicle increased the pollution and made it harder to live in the cities. This is the type of problem that never happened before in the history, because it was never so developed and crowded.

This was the problem that the dissertation work tried to investigate. It is important to start mitigation actions in everyday life today, even if the changes are making slightly difference, in order to keep our lives safe tomorrow.

Quality of life nowadays has nine different dimensions. In order to keep work with a good working material the chosen subject was discussed and studied. The subject of interest was to see what exactly is air pollution and noise, is it really so harmful and why.

Considering the fact that every city has individual local weather conditions, architecture, and environment, the mitigation actions are individual for each of them for reducing air pollution and noise. There are solutions for reduction of pollution, which can be only implemented in the city centres, or the opposite, in the areas outside the city.

For this reason, choosing key articles and scientific works was essential in order to provide the information for future mitigation work. In many cases some solutions are not providing progressive work and they may be even regressing the mitigation actions.

As the aim of this dissertation work was to find the key ways for decreasing air pollution and noise, the examples were chosen with the results, with the specific reduction, or the general idea, how each of them may have the efficiency in the cities or urban areas.

## **5.2 FUTURE STUDIES**

Based on the findings in this work the future work for deeper studies can be developed in order to apply the solutions to the city with the problems mentioned in the work, in order to check if the provided implementations can be useful for improving quality of life and act positively on the citizens and environment.

The chapter 5, where the aim was to adjust the methods to the certain city, revealed, that in order for the implementation to work, the data is needed about the polluted air and the levels of noise in the city and the particular areas.

The relevance of the subject is very important. The problems may seem local but they are creating some harmful effects globally. For this reason, the problem cannot be and should not be ignored.

There is a hope that provided work will help citizens to realize the importance of the provided subject and it will help countries to start mitigation actions.

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